

Article

Pedestrian Perceived Risk of Construction Obstructions and Barriers Identified via Image Segmentation

Taegwan Yoon ¹ , Minji Choi ² and Seulbi Lee ^{3,*}

¹ Department of Architectural Design and Engineering, Incheon National University, 119, Academy-ro, Yeonsu-gu, Incheon 22012, Republic of Korea; x8333x@inu.ac.kr

² Division of Architectural Engineering, Inha University, 100, Inha-ro, Michuhol-gu, Incheon 22212, Republic of Korea; mjchoi@inha.ac.kr

³ Division of Architecture & Urban Design, Incheon National University, 119, Academy-ro, Yeonsu-gu, Incheon 22012, Republic of Korea

* Correspondence: sblee@inu.ac.kr

Abstract: Pedestrian safety near construction sites is increasingly threatened by sidewalk obstructions such as materials and equipment. Despite growing attention to pedestrian-friendly environments, few studies have quantified how such visual encroachments affect the perceived risk. This study introduces a novel image-based framework that integrates the Segment Anything Model (SAM) for the object-level segmentation of sidewalks, obstructions, and barriers in 61 real-world street images. The results revealed significant differences in the perceived risk across four sidewalk environment types, defined by the presence or absence of obstructions and barriers. In addition, the proportion of sidewalk occupied by obstructions was strongly correlated with the perceived risk, whereas the relative size of barriers had no significant effect. This study provides a practical understanding of how temporary obstructions and barriers affect pedestrians' perceived risk, supporting more effective safety management in urban construction environments. It also contributes to advances in research by providing an objective method for assessing visible hazards using advanced image segmentation techniques.

Keywords: pedestrian safety; perceived risk; construction sites; image segmentation



Academic Editor: Igal Shohet

Received: 30 March 2025

Revised: 5 May 2025

Accepted: 7 May 2025

Published: 8 May 2025

Citation: Yoon, T.; Choi, M.; Lee, S. Pedestrian Perceived Risk of Construction Obstructions and Barriers Identified via Image Segmentation. *Appl. Sci.* **2025**, *15*, 5261. <https://doi.org/10.3390/app15105261>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

As construction projects continue to increase in densely populated urban areas, sidewalks adjacent to construction sites are often occupied by building materials and equipment [1–3]. Such occupation reduces the available pedestrian space, forcing pedestrians to navigate narrow or disrupted pathways and thereby compromising the overall quality of walking [4]. In severe cases, obstructed sidewalks compel pedestrians to detour onto vehicle roadways or other hazardous areas, increasing the risk of pedestrian accidents [5,6]. Given that pedestrian injuries arising from falls, slips, and trips significantly outnumber the reported fatalities yet remain unrecorded in official accident statistics [7–9], ensuring pedestrian safety near construction sites is a critical issue.

To guarantee safe walking conditions around construction sites, many regulations prohibit excessive encroachment that interferes with pedestrian flow unless an alternative pedestrian route is provided [10]. However, despite these clear guidelines, effective enforcement and implementation remain limited because construction sites are temporary and change rapidly [11–13]. Moreover, improper safety practices and insufficient attention to pedestrian safety exacerbate the challenges of conducting timely inspections and maintaining compliance [14,15].

In response to these issues, various studies have proposed methods to evaluate sidewalks in terms of pedestrian comfort and safety. For example, Rostiyanti et al. [12] conducted field observations to identify the potential risk factors affecting pedestrian safety on a temporary sidewalk near a light rail transit construction project in Indonesia. Although such expert-led audits provide in-depth, professional assessments of on-site conditions, they can be costly and time-consuming. Consequently, researchers have increasingly explored image- or virtual reality-based survey approaches. Lee et al. [16] asked pedestrians to rate their satisfaction and dissatisfaction by viewing real images of diverse walking environments. Li et al. [17] employed 360-degree panoramic street views enhanced with virtual reality technologies to identify scenes perceived as more pleasurable or safe for walking.

As image-based survey methods have become more common, researchers have adopted subjective indicators to capture pedestrians' evaluations of their walking environments. One such indicator is perceived risk, which refers to an individual's assessment of the potential danger in a given setting. Although the perceived risk may not directly correspond to the actual risk, it plays a critical role in safety research, as behavior is often guided by subjective perceptions rather than objective conditions [18,19]. For example, Kwon et al. [20] observed that pedestrians who recognize a heightened risk tend to walk in haste to avoid perceived hazards, which, paradoxically, increases the likelihood of engaging in risky behavior.

Building on this perspective, other studies have highlighted that objective environmental attributes can shape pedestrians' perceived risk and, in turn, influence their walking behavior. For example, Shuaib and Rana [21] found that the presence of abandoned waste and piled-up construction materials on sidewalks heightens pedestrians' perceived risk, leading many to avoid walking altogether. Conversely, Yoon and Lee [22] reported that physical buffers, such as barrier walls, can reduce pedestrians' perceived risk by providing a clear sense of separation and safety from nearby construction activity, thereby encouraging them to continue walking.

Although macro-level studies can capture general urban features, merely noting the presence or absence of specific objects reveals little about how these factors affect pedestrians' perceived risk [23]. In this context, researchers have introduced more fine-grained, micro-level approaches that examine factors such as surface materials, slopes, and width [2,11,24–27]. Among these, one widely used metric is the effective width, defined as the portion of sidewalk remaining available for pedestrians after accounting for obstructions. For example, Coppola and Marshall [24] developed a method using QGIS software to calculate the effective sidewalk width considering static objects, but it does not address temporary encroachments like construction materials. Nag and Goswami [11] developed a model that quantifies sidewalk encroachment with street images, but it required manual measurement by auditors, making it time-consuming and subjective. Ai and Tsai [26] advanced an automated sidewalk assessment method using three-dimensional mobile LiDAR and image processing, yet the data collection costs remain a significant barrier. Furthermore, while many studies have examined the general factors that reduce sidewalk width, relatively few have specifically measured the extent of obstructions arising from construction activities.

Therefore, this study aims to quantitatively investigate how variations in the available sidewalk space adjacent to construction sites influence pedestrians' perceived risk levels. Figure 1 shows the research framework of the study, which consists of four main stages. First, 61 street images (47 depicting construction sites and 14 showing normal sidewalks) were collected through a web-scraping approach. Next, 42 participants were asked to evaluate their perceived risk while imagining walking along the sidewalks shown in each image. Perceived risk was rated using a five-point Likert scale. In the third stage, the

Segment Anything Model (SAM) [28] was applied to generate pixel-level segmentation masks for sidewalks, obstructions, and barriers in each image. SAM is a recently introduced foundation model that generates pixel-level segmentation masks, which refer to the spatial areas corresponding to specified objects based on a visual input and user-defined prompts [28]. Its ability to segment complex scenes without task-specific training makes it particularly suitable for urban imagery involving construction zones. Finally, based on the extracted masks, two quantitative indicators—the obstruction–sidewalk ratio and the barrier–sidewalk ratio—were developed. These were used in a series of statistical analyses to explain variations in participants’ perceived risk based on objective visual features.

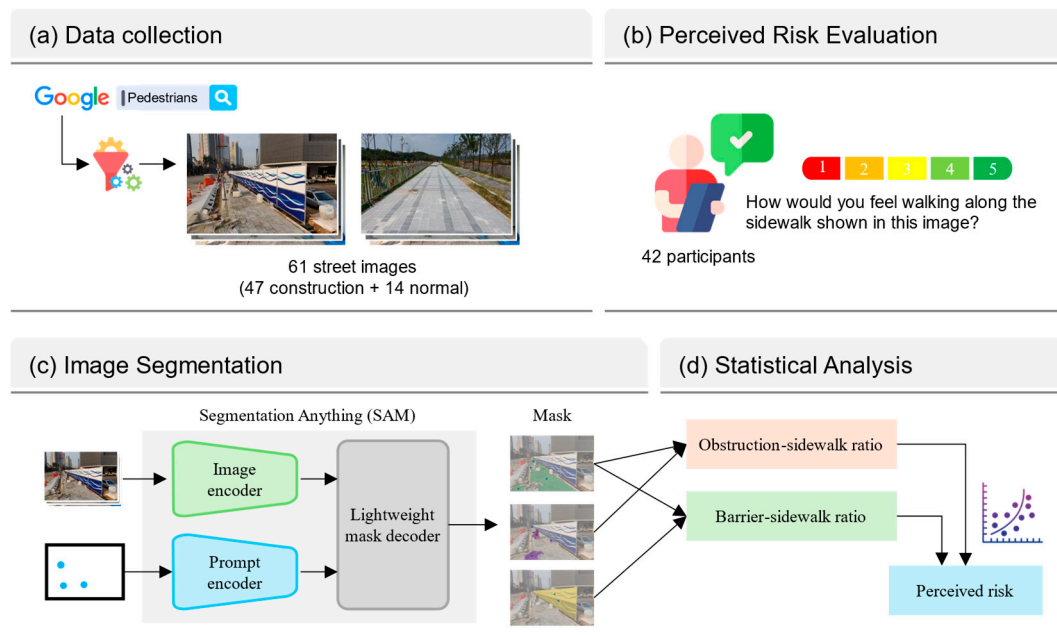


Figure 1. Research framework that illustrates the overall process of the study.

2. Materials and Methods

2.1. Data Gathering

Street images were gathered using a web-scraping approach that automatically retrieved pictures matching a predefined set of keywords [29]. Google Images served as the primary search engine, employing queries such as “construction sites”, “work zones”, “sidewalks”, “pedestrians”, “building materials”, “temporary pedestrian walkways”, and “pedestrian accidents”. These queries aimed to capture a wide range of sidewalk conditions adjacent to construction sites, resulting in the initial retrieval of approximately 300 images. Once retrieved, the images underwent a thorough screening process to ensure both relevance and consistent quality. Three researchers independently reviewed the collected images based on the following five key criteria. First, any images that did not clearly depict a sidewalk adjacent to a construction site were excluded from the dataset. Second, images containing pedestrians, apart from construction workers, were removed to minimize any potential effects attributable to personal or behavioral characteristics [30]. Third, to reduce the variability caused by differences in pavement materials and slopes, only sidewalks featuring brick-paved surfaces and flat gradients were retained. Fourth, images with resolutions below 320×320 or above 1920×1080 were excluded to ensure consistent visual clarity. Lastly, images containing large text overlays or visible watermarks were removed to avoid visual distractions. Ultimately, 47 images that met all five criteria were retained for analysis.

Because this study also aimed to compare obstructed sidewalks with unobstructed scenarios, an additional 14 images of normal sidewalks were collected to serve as a control dataset. Figure 2a presents an example of a typical construction site environment with barrier walls and building materials placed on the sidewalk, whereas Figure 2b depicts a representative normal urban sidewalk.



Figure 2. Street images: (a) a sidewalk adjacent to a construction site and (b) a normal sidewalk.

2.2. Participants and Sampling

An online survey was conducted to evaluate pedestrians' perceived risk for the sidewalks depicted in the 61 collected images—47 illustrating sidewalks adjacent to construction sites and 14 representing normal conditions. Participants were recruited through a poster that was publicly displayed on a university campus for approximately six weeks (between 1 July 2023, and 10 August 2023). The poster included information about the study's purpose, the estimated time commitment, and compensation for participation. Each participant received a mobile gift voucher equivalent to approximately USD 10 upon completion of the survey. To distribute rewards and prevent duplicate participation, mobile phone numbers were collected solely for one-time verification. These numbers were not linked to survey responses and were discarded after reward distribution.

The survey itself was administered through an online platform, and all responses were submitted anonymously. Prior to proceeding with the survey, participants were again informed about the general purpose of the study, the voluntary nature of their involvement, and their right to withdraw at any time without penalty. Informed consent was obtained from all participants before they began the survey. They were also assured that their responses would remain confidential. The research protocol was reviewed and approved by the Institutional Review Board of Incheon National University (Approval No.: 7007971-202305-010A).

Table 1 summarizes the demographic characteristics of the participants. A total of 42 individuals (33 males and 9 females) voluntarily participated in and completed the survey. This sample size is comparable to those used in similar image-based studies, which have typically recruited between 36 and 40 participants [17,31]. All participants were at least 20 years old, had experience walking along sidewalks adjacent to construction sites in urban areas, and reported no significant physical or mobility limitations. The majority of respondents (88.1%) were between 20 and 29 years old, which may reflect the university campus setting in which recruitment took place. In terms of the perceived sidewalk constraint, 64.3% of participants agreed or strongly agreed that the sidewalk became narrow due to construction work.

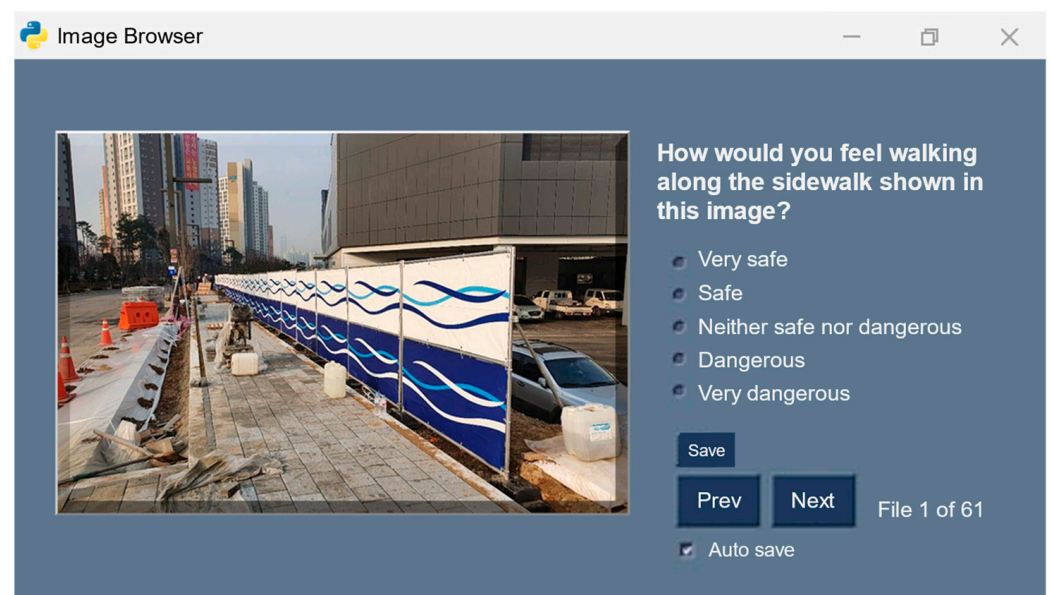
Table 1. Demographic characteristics of survey participants ($n = 42$).

Items	Categories	Frequency	Percentage (%)
Gender	Male	33	78.6
	Female	9	21.4
Age	20–29	37	88.1
	30–39	4	9.5
	40–49	1	2.4
	50–59	0	0.0
Experience *	Yes	42	100.0
	No	0	0.0
Perceived sidewalk constraint **	Strongly disagree	0	0.0
	Disagree	8	19.0
	Neutral	7	16.7
	Agree	21	50.0
	Strongly agree	6	14.3

* Based on the question, “Have you had experience walking along sidewalks adjacent to construction sites in urban areas?”. ** Based on the question, “Have you ever felt that the sidewalk became narrow due to construction work?”.

2.3. Perceived Risk Evaluation

The survey consisted of a straightforward evaluation designed to gauge pedestrians’ perceived risk based on street images. To facilitate user-friendly responses and ensure efficient data storage, a custom-built image evaluation program was developed using Python 3.12, as shown in Figure 3. Using this program, participants reviewed a total of 61 images and provided their responses in a consistent format. Referring to questions used in previous studies [32–34], only one standardized question was presented for each image: “How would you feel walking along the sidewalk shown in this image?” Response options were displayed using a five-point Likert scale: (1) very safe, (2) safe, (3) neither safe nor dangerous, (4) dangerous, or (5) very dangerous. The scale reflects the extent to which participants perceived the sidewalk as unsafe; thus, higher scores indicate a more dangerous walking environment. All images were displayed individually at the same size, and participants could either manually save each response or enable an auto-save option. To minimize ordering effects, the image sequence was randomized for each participant.

**Figure 3.** A custom-built image evaluation program developed for this study.

2.4. Image Segmentation

Following the collection and evaluation of street images, this study employed SAM to generate segmentation masks for objects potentially impacting pedestrian safety. SAM, recently developed by Kirillov et al. [28], constitutes a noteworthy advancement in computer vision by enabling real-time segmentation with minimal manual intervention. Designed as a foundation model for a broad range of segmentation tasks, SAM does not require an extensive training dataset and is therefore well suited to handling the complex nature of urban environments, where construction sites and pedestrians coexist [35–37].

As illustrated in Figure 4, SAM comprises three primary components: an image encoder, a prompt encoder, and a lightweight mask decoder. First, the image encoder processed each input image and transformed it into a high-dimensional embedding that captured global features such as color, texture, and object boundaries. Meanwhile, the prompt encoder accepted user-defined inputs indicating which elements to segment in the image. These prompts could range from a single point on the target object (point-prompt) to more sophisticated inputs like text descriptions (text-prompt). Finally, the lightweight mask decoder merged the outputs from both encoders and produced segmentation masks that outlined the specified objects.

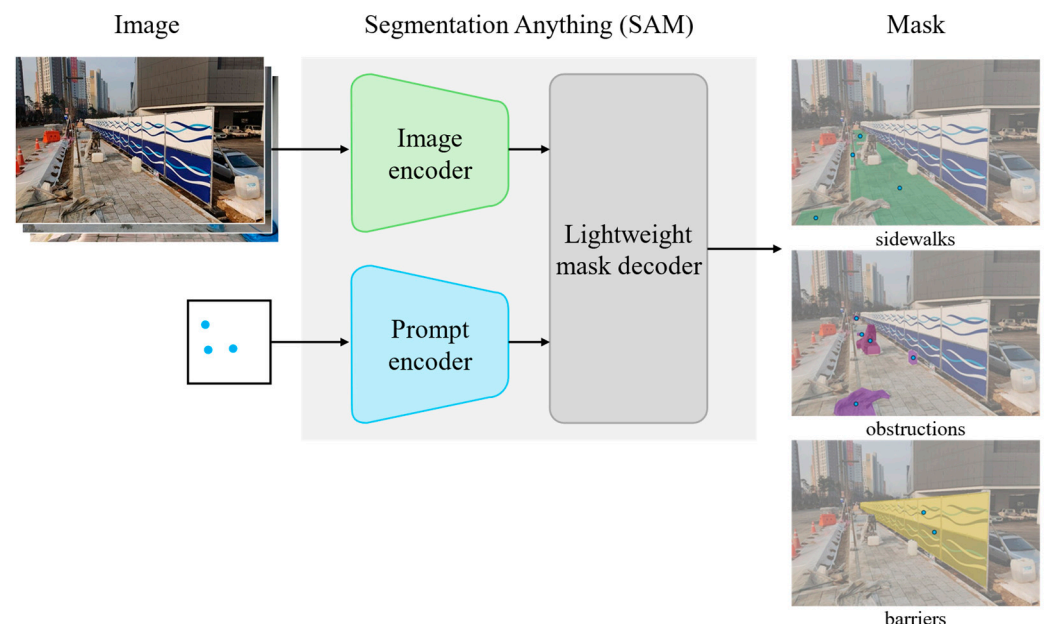


Figure 4. Street images segmentation process using SAM.

Because the goal of this study was to quantify how construction activity affects pedestrian safety, segmentation was applied to three object categories in each image: sidewalks, obstructions, and barriers. Sidewalks refer to continuous pedestrian walkways, forming the basis for evaluating the walkable environment (shown in green-colored masks in Figure 4). On the other hand, obstructions include materials, equipment, debris, or any other construction-related items encroaching on sidewalk space (shown in purple in Figure 4). Barrier walls and fences that separate pedestrian pathways from construction sites constitute the third category (shown in yellow in Figure 4). Although these barriers do not occupy sidewalk space in the same way as obstructions, they offer a degree of protection from adjacent hazards and may influence pedestrians' perceived risk.

In this study, the prompt encoder adopted a point-prompt approach. By clicking a single point on a specific object in the image, SAM automatically produced colored segmentation masks for each object class. The subsequent step involved translating these masks into quantifiable measures that could be compared across images of varying sizes.

To achieve this, the total number of pixels in the corresponding mask was counted for each object class (sidewalk, obstruction, and barrier). Although pixel counts do not directly correspond to real-world object size, the perceived size of objects in the images is likely to be the key factor influencing individuals' perceived risk [38,39]. Supporting this rationale, Berryhill and Olson [40] found that observers can reliably estimate object distances from 2D images with 94% accuracy, even though absolute distances tend to be underestimated. Accordingly, pixel-based measurements offer a theoretically sound proxy for perceived visual prominence.

To facilitate comparisons across images of varying resolutions or captured from different camera angles, the raw pixel counts were normalized by the total pixel area of each image. This yielded percentages for each object class that could be directly compared, regardless of differences in the image size or perspective. Subsequently, building on these basic pixel-based measures, two additional indices were developed to quantify how obstructions and barriers diminish the available space for pedestrians. First, the obstruction–sidewalk ratio was defined as the proportion of the nominal sidewalk area occupied by obstructions. Since SAM only extracted the visible sidewalk (portions not covered by obstructions), the nominal sidewalk area was calculated as the sum of the visible sidewalk and obstruction areas. For instance, if obstructions completely covered the sidewalk, the visible sidewalk area became zero, and the ratio approached 100%. Conversely, if there were no obstructions, the obstruction area was zero, resulting in a ratio of zero. Second, the barrier–sidewalk ratio was proposed to measure the extent to which barriers were present around sidewalk areas adjacent to construction zones. Unlike obstructions, barriers were not necessarily located on the sidewalk and could extend beyond its bounds. Consequently, the segmented barrier area could sometimes exceed the total nominal sidewalk area. In such cases, the ratio was capped at one to avoid distortion in the analysis. This approach assumes that once a barrier is large enough to fully enclose or demarcate the construction zone, and that an additional size does not further influence pedestrian perception.

2.5. Statistical Analysis

To bridge subjective risk assessments from the survey with the objective and numerical measures described in the previous sections, this study performed a series of statistical analyses. First, the study investigated whether participants' risk ratings differed significantly among four categories of sidewalk environments based on the presence (1) or absence (0) of obstructions (O) and barriers (B). These were labeled O0_B0, O0_B1, O1_B0, and O1_B1. For example, all 14 images in the control dataset, which represent scenes with neither obstructions nor barriers, were classified under the O0_B0 category. Because the dataset did not meet normality assumptions, the non-parametric Kruskal–Wallis test was employed to evaluate whether there was a statistically significant difference in the perceived risk among these four groups. Whenever the Kruskal–Wallis test indicated a significant effect ($p < 0.05$), Dunn's post hoc test was carried out to identify which specific pairs of groups differed. Next, the study examined the impact of the proportion of the sidewalk area occupied by obstructions and barriers denoted by the obstruction–sidewalk ratio and the barrier–sidewalk ratio, respectively. To investigate how increases in these ratios relate to perceived risk, both Spearman's rank correlation and ordinary least squares regression analyses were performed. Lastly, considering that some visible characteristics in images may not directly influence the perceived risk but might shape how participants interpret the built environment, this study explored the mediating effects of candidate variables on the relationship between the obstruction–sidewalk ratio and participants' perceived risk using a non-parametric, bootstrap-based approach.

3. Results

3.1. Differences in Perceived Risk Level

The Kendall coefficient of concordance (Kendall's W) was computed to evaluate the consistency among survey participants in ranking the perceived risk levels of street images [41]. The analysis yielded a Kendall's W value of 0.72 ($p < 0.001$), which falls within the range of 0.61 to 0.80, indicating a substantial level of agreement among raters [42]. This significant concordance suggests that participants share a common perceived risk for each street image, rather than making entirely individual subjective judgments.

Following this confirmation of the inter-rater consistency, a Kruskal–Wallis test was performed to examine whether the four sidewalk environments differed significantly in terms of perceived risk. The test revealed a significant overall effect, $H(3) = 1298.74$, $p < 0.001$, $\epsilon^2 = 0.51$, indicating that participants' risk ratings were influenced by the presence or absence of construction obstructions and barriers.

Specifically, as shown in Figure 5, the group with no obstructions and no barriers (O0_B0) exhibited the lowest perceived risk with a median of 2 and mean of 1.68. This group was the only one that did not involve a construction setting, serving as the control condition consisting of well-maintained sidewalks without adjacent construction activity, and was thus perceived as the safest scenario. In contrast, the remaining three groups (O1_B0, O1_B1, and O0_B1) all depicted sidewalks adjacent to construction sites, but with differing physical conditions. Sidewalks obstructed by construction materials or equipment but lacking any protective barriers (O1_B0) were rated as the most hazardous, receiving a median risk rating of 3 and a mean of 3.81. When obstructions were present but barriers were also placed (O1_B1), the median remained 3, and the mean perceived risk slightly decreased to 3.59, suggesting that barriers may offer pedestrians a sense of protection. Lastly, in the barrier-only group (O0_B1), which represents well-maintained sidewalks adjacent to construction sites, the median perceived risk was 2 and the mean was 2.21, indicating a level of risk lower than moderate. The descriptive statistics for each group are also presented in Table 2.

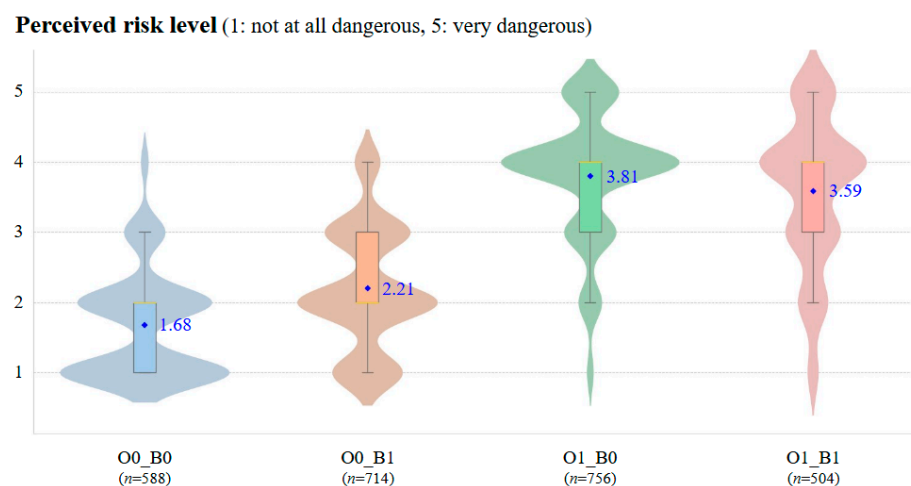


Figure 5. Mean and median perceived risk levels across sidewalk conditions.

Table 2. Group-wise descriptive statistics for perceived risk.

Group	<i>n</i>	Mean	Median	SD	IQR
O0_B0	588	1.68	2	0.77	1~2
O0_B1	714	2.21	2	0.87	2~3
O1_B0	756	3.81	3	0.89	3~4
O1_B1	504	3.59	3	1.06	3~4

Dunn's post hoc tests were conducted to identify which specific pairs of groups differed significantly, and the results are summarized in Table 3. All pairwise comparisons revealed statistically significant differences in the mean perceived risk levels. Five of the six comparisons were highly significant ($p < 0.001$), while the comparison between O0_B0 (obstructions without barriers) and O1_B1 (obstructions with barriers) showed a smaller yet still meaningful difference ($p < 0.05$). Among all pairs, the largest difference in the mean perceived risk was observed between O0_B0 (no obstructions, no barriers) and O1_B0, indicating the substantial impact of construction material encroachment into pedestrian space on perceived risk.

Table 3. Dunn's post hoc comparisons.

Comparison	Mean Difference	<i>p</i> -Value	Sig.
O0_B0 vs. O0_B1	−0.53	$p < 0.001$	***
O0_B0 vs. O1_B0	−2.12	$p < 0.001$	***
O0_B0 vs. O1_B1	−1.91	$p < 0.001$	***
O0_B1 vs. O1_B0	−1.60	$p < 0.001$	***
O0_B1 vs. O1_B1	−1.38	$p < 0.001$	***
O1_B0 vs. O1_B1	0.21	$p < 0.05$	*

Significance levels: * $p < 0.05$; *** $p < 0.001$.

3.2. Impact of Obstructions and Barriers

While the above analysis focused on the binary presence or absence of obstructions and barriers, this section explores how the quantitative extent of these objects affects pedestrians' perceived risk. To do so, two pixel-based ratios were used: the obstruction–sidewalk ratio and the barrier–sidewalk ratio. These indices were derived from SAM-based image segmentation, as described in Section 2.4.

Table 4 shows Spearman's rank correlation between the mean perceived risk levels and both the obstruction–sidewalk ratio and the barrier–sidewalk ratio, respectively. The results indicate that the obstruction–sidewalk ratio exhibited a significant, positive correlation with the mean perceived risk (Spearman's coefficient = 0.856, $p < 0.001$). In contrast, the barrier–sidewalk ratio showed no significant relationship with the mean perceived risk (Spearman's coefficient = −0.088, $p = 0.502$), suggesting that the relative size of barriers alone does not meaningfully alter pedestrians' ratings.

Table 4. Spearman rank correlation between pixel-based ratios and mean perceived risk.

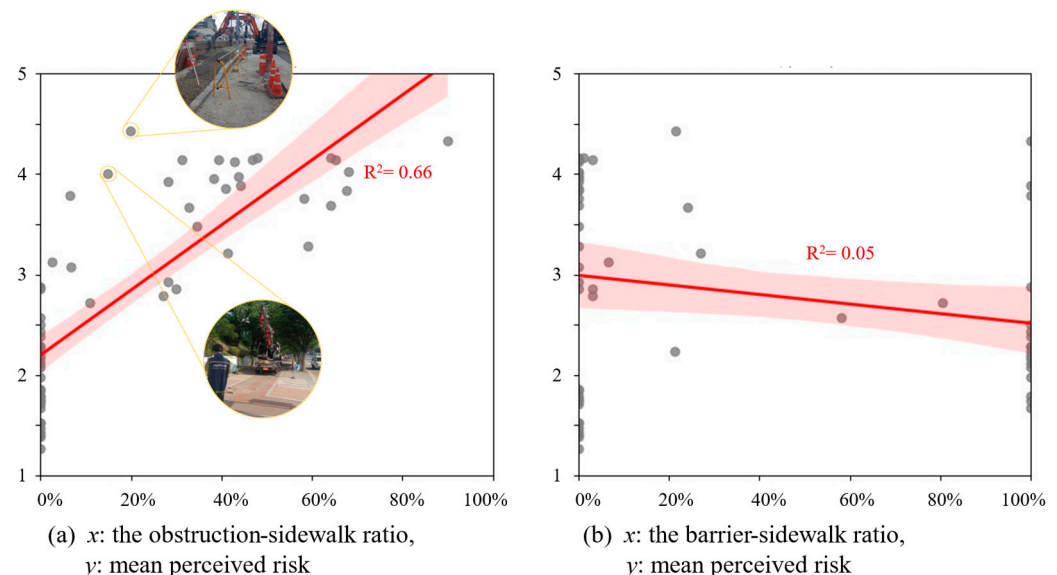
Variable	Spearman's Coefficient	<i>p</i> -Value
Obstruction–sidewalk ratio	0.86	$p < 0.001$
Barrier–sidewalk ratio	−0.09	0.502

In addition to the correlation analysis, an ordinary least squares regression was performed to determine whether the mean perceived risk could be estimated from the obstruction–sidewalk or barrier–sidewalk ratios. As shown in Table 5, when the obstruction–sidewalk ratio was used as the independent variable, the model achieved an R-squared value of 0.66 and was highly significant ($F = 112.4$, $p < 0.001$). The positive slope coefficient (3.24) confirmed that as obstructions occupy a greater portion of the sidewalk area, participants tend to perceive the environment as more dangerous. By contrast, when using the barrier–sidewalk ratio, the slope was negative (−0.4772), implying a potential trend whereby an increased barrier area might reduce the perceived risk. However, the model's explanatory power was limited ($R^2 = 0.05$) and statistically non-significant ($p = 0.092$).

Table 5. Results of ordinary least squares regression models.

Independent Variable	Model 1	Model 2
	Obstruction-sidewalk ratio	Barrier-sidewalk ratio
Intercept	2.20 (0.10)	2.99 (0.16)
Coefficient	3.24 (0.31)	−0.48 (0.28)
R ²	0.66	0.05
Adjusted R ²	0.65	0.03
F-statistics	112.4	2.93
p-value	<0.001	0.092
N	61	61

Figure 6 visualizes these regression results as scatter plots. Each gray dot represents one street image, and the red line indicates the fitted regression line with a 95% confidence interval. In Figure 6a, a clear positive linear relationship was observed between the obstruction–sidewalk ratio and the mean perceived risk. Conversely, a near-flat regression line in Figure 6b indicated no meaningful association between the barrier–sidewalk ratio and the mean perceived risk.

**Figure 6.** Scatter plots of pixel-based ratios and mean perceived risk.

A few outlier cases can also be observed from the plots. For example, one image showed a relatively high perceived risk level (~4.4) despite a low obstruction–sidewalk ratio (~20%), and another exhibited a similar pattern with a perceived risk of ~4.0 and an obstruction–sidewalk ratio of ~15%. To investigate the cause of these unexpected results, the corresponding images were reviewed. As a result, heavy construction equipment operating directly on the sidewalk was identified in both cases. This suggested that beyond the quantitative extent of obstructions, the type or visual characteristics of obstructions may also play a critical role in shaping the perceived risk.

3.3. Indirect Effects from Mediators

The barrier–sidewalk ratio itself did not exhibit a statistically significant direct effect on perceived risk; however, it may still influence participants' judgments indirectly, particularly when obstructions are present. Therefore, a third analysis was conducted to examine the potential mediating effects of the barrier–sidewalk ratio, focusing exclusively on images that contained obstructions (i.e., those in groups O1_B0 and O1_B1). Additionally, to

account for the visual characteristics observed in several outlier images—those perceived as dangerous despite exhibiting a low level of sidewalk encroachment—two more variables were introduced as potential mediators: the type of obstruction (1 = materials, 2 = heavy equipment) and the presence of construction workers (0 = No, 1 = Yes).

In a mediation framework, the path from the independent variable (X) to the mediator (M) is denoted by a , and the path from the mediator (M) to the dependent variable (Y), controlling for X, is denoted by b [43]. The indirect effect is typically computed as $a \times b$, while the direct effect (c') is the path from X to Y when M is included in the model. However, when the distribution of M is asymmetric, the estimated indirect effect may differ from the product of separately estimated a and b , because the bootstrap captures sampling variability across repeated resamples [44].

Figure 7 illustrates the conceptual mediation model tested in this third analysis. As shown in the diagram, the obstruction–sidewalk ratio (X) may exert an indirect influence on the perceived risk (Y) through one of three potential mediators (M): (1) the barrier–sidewalk ratio, (2) the type of obstruction (materials vs. heavy equipment), or (3) the presence of construction workers. Overall, the direct effect of the obstruction–sidewalk ratio on perceived risk ranged from 0.202 to 0.211. This indicates that, holding other factors constant, a one-unit (%) increase in the obstruction–sidewalk ratio is associated with an approximate 0.2 unit increase in the perceived risk. In practical terms, this finding reaffirms that increasing the area of obstruction leads to a higher perceived risk.

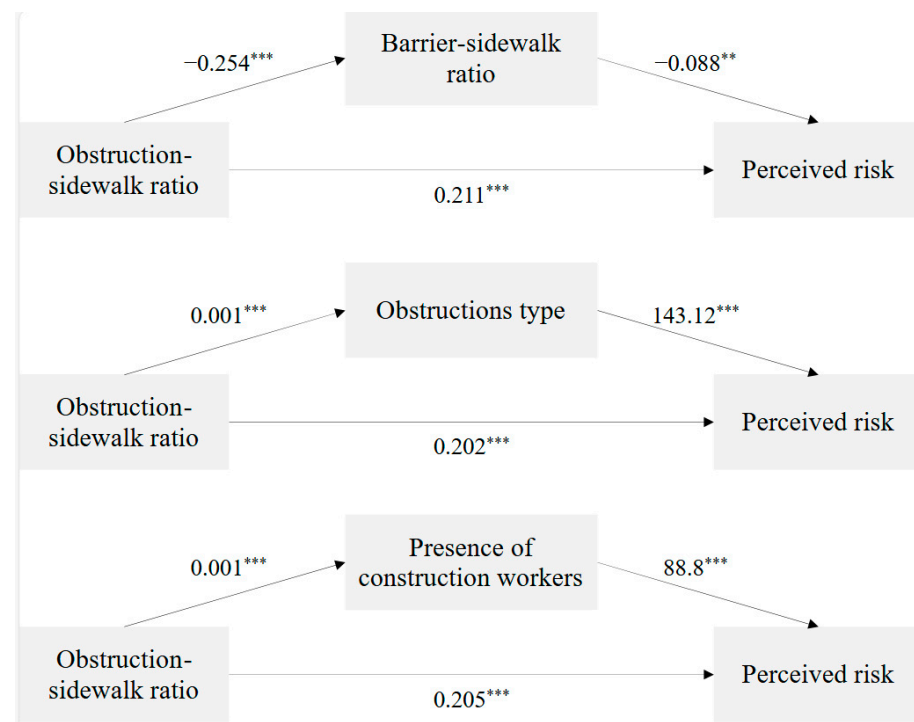


Figure 7. Conceptual mediation models (** $p < 0.01$, *** $p < 0.001$).

For the two potential mediators—obstruction type and the presence of construction workers—both path coefficients (a and b) were positive. Notably, b for the obstruction type was extremely large (143.12), and b for the presence of construction workers was also sizable (88.8). These large b values suggest that when the obstruction is heavy equipment rather than materials, or when construction workers are present rather than absent, even relatively small changes in the obstruction–sidewalk ratio can result in substantial increases in the perceived risk. In contrast, when considering the barrier–sidewalk ratio as a mediator, both a and b were negative. This implies that as the obstruction–sidewalk ratio increases,

the barrier–sidewalk ratio tends to decrease, and a lower barrier–sidewalk ratio is then associated with a higher perceived risk.

Table 6 presents the results of the mediation analysis using a rank-based, non-parametric, bootstrap procedure (5000 resamples) [36]. Among the three candidate mediators, both the obstruction type and the presence of construction workers mediated the association between the obstruction–sidewalk ratio and perceived risk (i.e., their 95% confidence intervals did not include zero) [36]. Specifically, obstruction type exhibited the strongest mediating role, with a bootstrap-estimated indirect effect of 0.069 and a 95% confidence interval [0.027, 0.124]. This suggests that pedestrians tend to perceive heavy equipment as more hazardous than materials when these obstructions are encountered on the sidewalk. Similarly, the presence of construction workers also acted as a significant mediator, with an indirect effect of 0.064 and a 95% confidence interval [0.020, 0.126]. This may be explained by the fact that the presence of construction workers indicates ongoing construction activities, which heighten perceptions of danger compared to scenes containing only construction materials. In contrast, the barrier–sidewalk ratio did not yield a statistically significant mediation effect (indirect effect = 0.005, 95% CI [−0.001, 0.020]).

Table 6. Indirect effects of the candidate mediators.

Mediator	Indirect Effect	Bootstrap 95% CI		Sig. *
		Lower	Upper	
Barrier-sidewalk ratio (%)	0.005	−0.001	0.020	No
Obstructions type (1 = materials, 2 = heavy equipment)	0.069	0.027	0.124	Yes
Presence of construction workers (0 = No, 1 = Yes)	0.064	0.020	0.126	Yes

* Significance was determined based on whether the 95% confidence interval included zero.

4. Discussion

4.1. Major Findings

This study demonstrated that pedestrians generally perceive sidewalks adjacent to construction sites as more dangerous environments. In particular, by quantitatively measuring the available sidewalk space in each street image, this study also found a strong positive correlation between the proportion of the area occupied by obstructions and the mean perceived risk. This finding supports the results of previous studies that have shown the adverse impact of construction sites on pedestrian safety in urban settings [1,12,21,22]. In addition, this finding is in line with studies that have highlighted the importance of maintaining a sufficient sidewalk width to ensure walking comfort and safety [11,24,26].

Another notable finding of this study is that the presence of barriers designed to separate pedestrians from hazardous areas reduces perceived risk. This result is highly relevant to previous studies indicating that pedestrian accident rates decrease significantly when sidewalks and buffers collectively provide protective space, compared to sidewalks alone [45]. However, beyond these conventional insights, this study also suggests that the overall size (i.e., area) of these barriers does not exhibit a statistically significant relationship with perceived risk. One possible explanation is that the protective effect of barriers may depend more on their vertical dimension or continuity rather than their horizontal extent. For example, one study demonstrated that tall, continuous barriers are associated with a substantially lower risk of cyclist collisions compared to lighter, low barriers [46].

Lastly, this study found that the type of obstruction and the presence of construction workers can play mediating roles in shaping perceived risk. These outcomes corroborate several studies indicating that moving objects—such as heavy equipment and construction workers—amplify the perceived risk because they make it more difficult for pedestrians

to anticipate their movement [47,48]. Furthermore, the findings confirmed that additional efforts toward the quantitative assessment of various visible objects are essential for creating a pedestrian-safe environment.

4.2. Practical Implications

The findings of this study can directly inform construction safety management practices, regulatory enforcement, and urban planning efforts aimed at reducing the potential risk posed to pedestrians near construction sites. For example, as shown in Figure 6a, this study found that when sidewalks are obstructed by construction-related materials or equipment by more than 25%, participants perceive the walking environment as unsafe (i.e., the mean perceived risk exceeds 3). Therefore, policymakers can consider implementing guidelines that impose fines when the obstruction exceeds one-quarter of the available sidewalk space. Furthermore, construction managers or urban planners might consider using the image segmentation model provided in this study as part of advanced surveillance technologies to monitor and minimize encroachments on pedestrian walkways in real time. Such quantitative methods employed in this study demonstrate the potential of data-driven approaches in evaluating and improving pedestrian safety. Ultimately, this study contributes not only to the immediate identification of hazardous areas adjacent to construction sites, but also to the development of long-term strategies for pedestrian-friendly urban infrastructure.

4.3. Limitations of the Research

Although this study addresses a real and pressing safety issue related to construction sites, particularly concerning pedestrians, there are still several limitations. First, the study relied solely on image-based evaluations without incorporating the direct observation of pedestrian behavior in real-world settings. While the controlled nature of image-based surveys enables the systematic assessment of visual factors, it limits our ability to capture dynamic pedestrian responses to evolving construction environments. For example, Li et al. [49] analyzed video footage recorded by camera-equipped drones to extract pedestrian trajectories and detect abnormal behaviors, including sudden changes in direction, abrupt stops, or unexpected accelerations. In this context, future studies should aim to develop citywide real-time surveillance systems capable of detecting unsafe pedestrian behaviors induced by construction activities.

Second, this study simplified the range of visual factors influencing pedestrians' perceived risk by focusing primarily on flat, paved sidewalks and considering only the areas occupied by obstructions and barriers. Other important attributes, such as the obstruction type, barrier height, and barrier color, were not evaluated. However, previous studies have found that the color and shape of safety signs can significantly influence pedestrians' risk-taking behavior and perceived risk [50]. In addition, common visual elements in urban environments, including scaffolding and warning signs, were not incorporated into the analysis. Therefore, to achieve a more in-depth understanding of pedestrian behavior and to improve the generalizability of the findings, future studies should expand the model to account for a wider variety of environmental features and visual factors.

Third, although the SAM was effective in generating segmentation masks with minimal user input, the current study still required manual verification and occasional corrections to ensure segmentation accuracy. Its performance under complex real-world conditions, particularly for potential applications in real-time surveillance systems, has not yet been validated. To address this limitation, future studies will propose advanced models aimed at enhancing accuracy by leveraging few-shot learning algorithms, which enable models to generalize effectively from only a small number of labeled examples [51].

Lastly, although the study analyzed 2562 responses (evaluations of 61 images by 41 participants), a larger sample could enhance the generalizability of the findings. In addition, San-Juan-Escudero et al. [31] have demonstrated demographic differences in pedestrians' perception of risk, such as older adults exhibiting greater dissatisfaction when encountering obstacles that impede walking, or women expressing heightened concerns in environments with inadequate lighting. Considering these points, future studies should aim to recruit a larger and more demographically diverse sample to better capture potential variations in perceived risk related to factors such as age, gender, and mobility.

5. Conclusions

Although ensuring pedestrian safety near construction sites is a critical responsibility in construction safety management, the illegal encroachment of construction materials and equipment onto sidewalks continues to place pedestrians in hazardous situations. This study quantitatively investigated how changes in the pedestrian environment caused by construction-related objects influence perceived risk levels, using segmentation masks generated by the SAM. To collect pedestrian safety evaluation data, an online survey was conducted in which 42 participants rated their perceived risk for each of the 61 street images. The statistical analysis bridging subjective risk ratings and objective measures can be summarized into three key findings. First, the presence or absence of obstructions and barriers significantly influenced the perceived risk. Second, while the degree of sidewalk obstruction showed a strong positive correlation with the perceived risk, the relative size of barriers did not significantly affect the perceived risk. Third, certain visible characteristics in street images, such as the obstruction type and the presence of construction workers, indirectly influenced the perceived risk.

This study provides a better understanding of how temporary obstructions and barriers affect pedestrians' perceived risk near construction sites. This study also offers an objective method to assess visible hazards by utilizing advanced image segmentation techniques. Despite these contributions, several limitations remain. First, this study relied solely on image-based evaluations and was unable to capture pedestrian behavior in real-world settings. Second, although the sample street images were carefully selected, the range of visual factors considered was relatively limited. Third, the segmentation accuracy of the fully automated SAM model under complex real-world conditions has not yet been validated. Fourth, the limited sample size and lack of demographic diversity may restrict the generalizability of the findings. Therefore, future studies should focus on developing real-time surveillance systems to monitor unsafe pedestrian behaviors induced by construction activities through CCTV data. In particular, such systems should incorporate various visual features, including barrier height, color, material type, and other urban elements, to deepen our understanding of risk perception. Methodological advancements, such as the application of few-shot learning algorithms, are also necessary to enhance segmentation accuracy under diverse real-world conditions. Additionally, future studies should recruit larger and more diverse samples to better examine how demographic characteristics influence pedestrians' perception of risk.

Author Contributions: Conceptualization, T.Y. and S.L.; methodology, S.L.; data curation, T.Y.; formal analysis, T.Y.; validation, M.C. and S.L.; writing—original draft preparation, T.Y.; writing—review and editing, M.C. and S.L.; funding acquisition, S.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Incheon National University (International Cooperative) Research Grant in 2022 (No. 2022-0262).

Institutional Review Board Statement: The study was approved by the Institutional Review Board of Incheon National University (Approval No.: 7007971-202305-010A and Date of Approval: 28 June 2023).

Informed Consent Statement: Informed consent for participation was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ibrahim, A.; El-Anwar, O.; Marzouk, M. Socioeconomic impact assessment of highly dense-urban construction projects. *Autom. Constr.* **2018**, *92*, 230–241. [\[CrossRef\]](#)
2. Müller, A.P.S.; Dorneles, V.G.; Ruiz-Padillo, A. Fuzzy geostatistical evaluation of micro-scale attributes of sidewalk accessibility: A Brazilian case. *Transp. Res. Part D Transp. Environ.* **2024**, *126*, 104018. [\[CrossRef\]](#)
3. Pérez-Delhoyo, R.; Andújar-Montoya, M.D.; Mora, H.; Gilart-Iglesias, V.; Mollá-Sirvent, R.A. Participatory management to improve accessibility in consolidated urban environments. *Sustainability* **2021**, *13*, 8323. [\[CrossRef\]](#)
4. Gebremariam, D.; Kuhilen, T.; Seboka, H.; Grum, B. Effect of Sidewalk Design and Obstructions on Pedestrian Mobility: A Case Study of the Main Streets of Mekelle City, Northern Ethiopia. *Adv. Civ. Eng.* **2024**, *2024*, 5672280. [\[CrossRef\]](#)
5. Mukherjee, D.; Mitra, S. Identification of pedestrian risk factors using negative binomial model. *Transp. Dev. Econ.* **2020**, *6*, 4. [\[CrossRef\]](#)
6. Jahangir, S.; Bailey, A.; Hasan, M.M.U.; Hossain, S. Inequalities in accessing public transportation and social exclusion among older adults and people with disabilities in Bangladesh: A scoping review. *Transp. Res. Interdiscip. Perspect.* **2024**, *26*, 101138. [\[CrossRef\]](#)
7. Methorst, R.; Schepers, P.; Christie, N.; Dijst, M.; Risser, R.; Sauter, D.; Van Wee, B. ‘Pedestrian falls’ as necessary addition to the current definition of traffic crashes for improved public health policies. *J. Transp. Health* **2017**, *6*, 10–12. [\[CrossRef\]](#)
8. Schepers, P.; den Brinker, B.; Methorst, R.; Helbich, M. Pedestrian falls: A review of the literature and future research directions. *J. Saf. Res.* **2017**, *62*, 227–234. [\[CrossRef\]](#)
9. Amin, K.; Skyving, M.; Bonander, C.; Krafft, M.; Nilson, F. Fall-and collision-related injuries among pedestrians in road traffic environment—A Swedish national register-based study. *J. Saf. Res.* **2022**, *81*, 153–165. [\[CrossRef\]](#)
10. Rannila, P.; Mitchell, D. Syracuse, sidewalks, and snow: The slippery realities of public space. *Urban Geogr.* **2016**, *37*, 1070–1090. [\[CrossRef\]](#)
11. Nag, D.; Goswami, A.K. Measuring the built walking environment through image calibration using a hybrid audit approach. *J. Transp. Eng. Part A Syst.* **2022**, *148*, 04022092. [\[CrossRef\]](#)
12. Rostiyanti, S.F.; Hansen, S.; Siregar, P.H.; Jodie, Z. Evaluation of nonconformity to pedestrian safety measure in immediate area of LRT Cawang-Dukuh Atas construction site. *J. Rekayasa Sipil* **2020**, *16*, 154–165. [\[CrossRef\]](#)
13. Alsultan, S.M.; Alqahtani, F.K.; Alkahtani, K.F. Health and safety in temporary work zone road construction project in Saudi Arabia: Risks and solutions. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10627. [\[CrossRef\]](#)
14. Kim, H.; Lim, H. A Study on the Importance and the Necessity of Simplification of Construction Safety Manager’s Work. *Korean J. Constr. Eng. Manag.* **2021**, *22*, 50–58.
15. Lee, J.; Jung, Y. Legislative Policy Assignments in Construction Project Management by Strengthening Safety-Related Laws-Focusing on the CM/supervision-related system. *Korean J. Constr. Eng. Manag.* **2022**, *23*, 76–88.
16. Lee, M.; Kim, S.; Kim, H.; Hwang, S. Pedestrian visual satisfaction and dissatisfaction toward physical components of the walking environment based on types, characteristics, and combinations. *Build. Environ.* **2023**, *244*, 110776. [\[CrossRef\]](#)
17. Li, Y.; Yabuki, N.; Fukuda, T. Measuring visual walkability perception using panoramic street view images, virtual reality, and deep learning. *Sustain. Cities Soc.* **2022**, *86*, 104140. [\[CrossRef\]](#)
18. Rana, I.A.; Routray, J.K. Actual vis-à-vis perceived risk of flood prone urban communities in Pakistan. *Int. J. Disaster Risk Reduct.* **2016**, *19*, 366–378. [\[CrossRef\]](#)
19. Rankavat, S.; Tiwari, G. Influence of actual and perceived risks in selecting crossing facilities by pedestrians. *Travel Behav. Soc.* **2020**, *21*, 1–9. [\[CrossRef\]](#)
20. Kwon, J.-H.; Kim, J.; Kim, S.; Cho, G.-H. Pedestrians safety perception and crossing behaviors in narrow urban streets: An experimental study using immersive virtual reality technology. *Accid. Anal. Prev.* **2022**, *174*, 106757. [\[CrossRef\]](#)
21. Shuaib, A.; Rana, M.M.P. Questing a walkable city: A case of urban neighbourhood walkability environment in Bangladesh. *J. Place Manag. Dev.* **2022**, *15*, 374–395. [\[CrossRef\]](#)

22. Yoon, T.; Lee, S. Identifying Environmental Factors near Construction Sites Affecting Pedestrian Safety. *Proc. Int. Conf. Constr. Eng. Proj. Manag.* **2024**, *10*, 7.
23. Baek, J.; Lim, L. Unveiling pedestrian injury risk factors through integration of urban contexts using multimodal deep learning. *Sustain. Cities Soc.* **2024**, *101*, 105168. [\[CrossRef\]](#)
24. Coppola, N.A.; Marshall, W.E. Sidewalk static obstructions and their impact on clear width. *Transp. Res. Rec.* **2021**, *2675*, 200–212. [\[CrossRef\]](#)
25. Aghaabbasi, M.; Moeinaddini, M.; Shah, M.Z.; Asadi-Shekari, Z.; Kermani, M.A. Evaluating the capability of walkability audit tools for assessing sidewalks. *Sustain. Cities Soc.* **2018**, *37*, 475–484. [\[CrossRef\]](#)
26. Ai, C.; Tsai, Y. Automated sidewalk assessment method for Americans with disabilities act compliance using three-dimensional mobile lidar. *Transp. Res. Rec.* **2016**, *2542*, 25–32. [\[CrossRef\]](#)
27. Ujjwal, J.; Bandyopadhyaya, R. Development of comprehensive service quality assessment framework for sidewalks considering desired and actual conditions. *Transp. Lett.* **2023**, *15*, 227–241. [\[CrossRef\]](#)
28. Kirillov, A.; Mintun, E.; Ravi, N.; Mao, H.; Rolland, C.; Gustafson, L.; Xiao, T.; Whitehead, S.; Berg, A.C.; Lo, W.-Y. Segment anything. In Proceedings of the IEEE/CVF International Conference on Computer Vision, Paris, France, 1–6 October 2023; pp. 4015–4026.
29. Khder, M.A. Web scraping or web crawling: State of art, techniques, approaches and application. *Int. J. Adv. Soft Comput. Its Appl.* **2021**, *13*, 145–168. [\[CrossRef\]](#)
30. Schneider, S.; Bengler, K. Virtually the same? Analysing pedestrian behaviour by means of virtual reality. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *68*, 231–256. [\[CrossRef\]](#)
31. San-Juan-Escudero, A.; Ballesteros-Peña, S.; Fernández-Aedo, I.; Sánchez, S.C.; Fernandez-Alonso, J.; Gullón, P.; Franco, M.; Gravina, L. Exploring urban design's impact on physical activity: A participatory photovoice study across socioeconomically diverse neighborhoods. *Landsc. Urban Plan.* **2025**, *259*, 105334. [\[CrossRef\]](#)
32. White, M.; Langenheim, N.; Yang, T.; Paay, J. Informing streetscape design with citizen perceptions of safety and place: An immersive virtual environment E-participation method. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1341. [\[CrossRef\]](#) [\[PubMed\]](#)
33. Vallejo-Borda, J.A.; Cantillo, V.; Rodriguez-Valencia, A. A perception-based cognitive map of the pedestrian perceived quality of service on urban sidewalks. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *73*, 107–118. [\[CrossRef\]](#)
34. Hidayati, I.; Tan, W.; Yamu, C. How gender differences and perceptions of safety shape urban mobility in Southeast Asia. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *73*, 155–173. [\[CrossRef\]](#)
35. Cao, Y.; Yang, P.; Xu, M.; Li, M.; Li, Y.; Guo, R. A novel method of urban landscape perception based on biological vision process. *Landsc. Urban Plan.* **2025**, *254*, 105246. [\[CrossRef\]](#)
36. Ho, Y.H.; Li, L.; Mostafavi, A. Integrated vision language and foundation model for automated estimation of building lowest floor elevation. *Comput.-Aided Civ. Infrastruct. Eng.* **2025**, *40*, 75–90. [\[CrossRef\]](#)
37. Akhavi Zadehan, A.; Vivet, D.; Hadachi, A. DELTA: Integrating multimodal sensing with micromobility for enhanced sidewalk and pedestrian route understanding. *Sensors* **2024**, *24*, 3863. [\[CrossRef\]](#) [\[PubMed\]](#)
38. Minelli, A.; Marchesini, I.; Taylor, F.E.; De Rosa, P.; Casagrande, L.; Cenci, M. An open source GIS tool to quantify the visual impact of wind turbines and photovoltaic panels. *Environ. Impact Assess. Rev.* **2014**, *49*, 70–78. [\[CrossRef\]](#)
39. Cimburova, Z.; Blumentrath, S. Viewshed-based modelling of visual exposure to urban greenery—An efficient GIS tool for practical planning applications. *Landsc. Urban Plan.* **2022**, *222*, 104395. [\[CrossRef\]](#)
40. Berryhill, M.; Olson, I.R. The representation of object distance: Evidence from neuroimaging and neuropsychology. *Front. Hum. Neurosci.* **2009**, *3*, 693. [\[CrossRef\]](#)
41. Gearhart, A.; Booth, D.T.; Sedivec, K.; Schauer, C. Use of Kendall's coefficient of concordance to assess agreement among observers of very high resolution imagery. *Geocarto Int.* **2013**, *28*, 517–526. [\[CrossRef\]](#)
42. Landis, J.R.; Koch, G.G. The measurement of observer agreement for categorical data. *Biometrics* **1977**, *33*, 159–174. [\[CrossRef\]](#) [\[PubMed\]](#)
43. Fairchild, A.J.; MacKinnon, D.P. A general model for testing mediation and moderation effects. *Prev. Sci.* **2009**, *10*, 87–99. [\[CrossRef\]](#)
44. MacKinnon, D.P.; Lockwood, C.M.; Williams, J. Confidence limits for the indirect effect: Distribution of the product and resampling methods. *Multivar. Behav. Res.* **2004**, *39*, 99–128. [\[CrossRef\]](#)
45. Hanson, C.S.; Noland, R.B.; Brown, C. The severity of pedestrian crashes: An analysis using Google Street View imagery. *J. Transp. Geogr.* **2013**, *33*, 42–53. [\[CrossRef\]](#)
46. Cicchino, J.B.; McCarthy, M.L.; Newgard, C.D.; Wall, S.P.; DiMaggio, C.J.; Kulie, P.E.; Arnold, B.N.; Zuby, D.S. Not all protected bike lanes are the same: Infrastructure and risk of cyclist collisions and falls leading to emergency department visits in three US cities. *Accid. Anal. Prev.* **2020**, *141*, 105490. [\[CrossRef\]](#) [\[PubMed\]](#)
47. Son, S.-O.; Park, J.; Oh, C.; Yeom, C. An algorithm for detecting collision risk between trucks and pedestrians in the connected environment. *J. Adv. Transp.* **2021**, *2021*, 9907698. [\[CrossRef\]](#)

48. Duarte, J.; Marques, A.T.; Santos Baptista, J. Occupational accidents related to heavy machinery: A systematic review. *Safety* **2021**, *7*, 21. [[CrossRef](#)]
49. Li, T.; Hu, C.; Sze, N.; Sun, Z.; Ding, H.; Chen, T. Modelling pedestrian-vehicle interaction behaviours at non-signalised crosswalks using a game theory approach incorporating the risk perception. *Transp. A Transp. Sci.* **2025**, 1–31. [[CrossRef](#)]
50. Ahmed, J.; Robinson, A.; Miller, E.E. Effectiveness of signs for pedestrian-railroad crossings: Colors, shapes, and messaging strategies. *J. Saf. Res.* **2024**, *89*, 141–151. [[CrossRef](#)]
51. Wang, Y.; Yao, Q.; Kwok, J.T.; Ni, L.M. Generalizing from a few examples: A survey on few-shot learning. *ACM Comput. Surv. (CSUR)* **2020**, *53*, 1–34. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.