PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 29 No. 3 pp: 120:131

Exploring Key Factors Influencing Pedestrian Street Vitality in Downtown Cairo

Heba Adel Ahmed Hussein[1,*]

[1] *Architectural Engineering and Urban planning Department, Faculty of Engineering, Port Said University, Port Said, Egypt*
email: heba.adel@eng.psu.edu.eg

**Corresponding author,* *DOI: 10.21608/pserj.2025.366996.1398*

Received 10-3-2025,
Revised 25-4-2025,
Accepted 7-5-2025

ABSTRACT

As part of the Egyptian government's redevelopment plan for Downtown Cairo following the relocation of government ministries to the New Administrative Capital, select streets will be pedestrianized. While pedestrianization offers multiple benefits, underutilized streets may become unsafe, potentially fostering crime and antisocial behavior. Research suggests that street vitality is essential for maintaining safe, attractive, and active pedestrian spaces. In this context, this study investigates key factors influencing pedestrian street vitality in Downtown Cairo to guide future planning efforts. Six study streets were selected, and potential influencing factors identified through a literature review were measured across these streets using semantic segmentation, ArcGIS, ENVI-met, and on-site observations. Pedestrian count was used as an indicator of vitality. Pearson correlation analysis, principal component analysis, and multiple linear regression were applied to assess the impact of these factors on vitality. The results indicate that the width of pedestrian-designated spaces, street length, number of mini-markets, total number of stores, diversity of street functions, proximity to residential areas, and number of commercial display elements have a strong, positive and statistically significant impact on street vitality. These findings highlight the importance of strategic street selection and activity planning in future redevelopment projects to create vibrant, well-utilized pedestrian spaces.

Keywords: Street vitality, Street safety, Pedestrian streets, Downtown Cairo, Semantic segmentation.

1 INTRODUCTION

In conjunction with the relocation of government ministries to the New Administrative Capital (NAC), the Egyptian government has initiated a plan to redevelop Downtown Cairo. This plan includes converting the vacated government buildings into luxury hotels and pedestrianizing select streets [1]. Pedestrianizing streets can help reduce vehicle-related air pollution, minimize pedestrian accidents, encourage walking, increase foot traffic, and create spaces for social interaction. These changes, in turn, can contribute to a healthier and more sustainable urban environment while fostering a sense of community [2]. However, pedestrianizing streets may raise safety concerns. Studies have shown that empty or under-utilized pedestrian streets can become magnets for crime and antisocial behavior, particularly at night [3], [4].

In response to such challenges, Jane Jacobs [5] argued that a vibrant street life, with 'eyes on the street' from residents and businesses, is crucial for fostering a sense of street safety. She emphasized that this can be achieved by increasing the number of users, diversifying street activities, and ensuring a consistent flow of activity throughout the day. Expanding on Jacobs' ideas, Oscar Newman [6] examined how active storefronts contribute to street vitality, which in turn promotes natural surveillance. He argued that high-vitality streets, characterized by a mix of commercial and residential activities, tend to have lower crime rates due to the constant presence of people, which deters criminal behavior.

Similarly, Cohen and Felson [7] argued that vibrant streets with high levels of activity, where people are continuously present and engaged, can reduce the opportunities for criminal behavior. In this regard, they introduced the concept of the ‘crime triangle’, which suggests that crime occurs when three elements converge: a motivated offender, a suitable target, and a lack of capable guardianship. Furthermore, Gehl and Svarre [8] introduced a ‘people-centric’ approach to designing lively streets, suggesting that creating inviting public spaces can inherently promote safety through increased social interaction and human presence.

More recently, the concept of ‘social infrastructure’, as articulated by Eric Klinenberg [9], has further expanded the understanding of safety and street vitality. Klinenberg argued that well-designed, pedestrianized streets serve as essential infrastructure for building strong, connected communities. These spaces encourage routine social interactions, which help foster trust, mutual support, and informal social control. According to Klinenberg, when people have regular opportunities to encounter and engage with one another in shared urban spaces, communities become more resilient and less prone to crime or disorder. Together, these theories and frameworks provide a robust foundation for understanding and enhancing street vitality.

In light of the above, this study investigates key factors influencing pedestrian street vitality in Downtown Cairo to guide future planning and ensure future pedestrianized streets are safe, attractive, and well-utilized. The remainder of this paper is structured as follows: Section 2 provides a brief literature review on street vitality and its influencing factors. Section 3 outlines the methodology, including the selection of study streets, the measurement of the identified factors, and the statistical methods used. Section 4 presents the results and discusses their implications. Finally, Section 5 provides the conclusion and highlights the research limitations.

2 LITERATURE REVIEW

2.1 Street Vitality

Street vitality refers to the degree to which a street is active, engaging, and used by a diverse range of people throughout the day and night. In other words, it reflects the concentration of people and activities in a given street space [10]. To quantify street vitality, early studies relied on direct pedestrian counts. For instance, March et al. [11] manually recorded pedestrian numbers on selected streets to gauge activity levels. Similarly, Xu et al. [12] introduced a vitality metric based on the average number of active people observed in specific locations. However, these methods are susceptible to human error, especially in crowded or fast-moving environments, potentially leading to inaccuracies in counting.

With technological advancements, new real-time indicators have emerged, allowing for more efficient and scalable analysis. Liu et al. [10] utilized Baidu heat maps to estimate the spatial distribution of street users and infer vitality levels, offering a broader and more dynamic perspective. Wu et al. [13] analyzed mobile location data to track users’ coexistence on selected streets, providing a more continuous and automated assessment of street activity. Abdel-Rasoul [14] leveraged social media check-ins to measure vitality, demonstrating the potential of crowdsourced data in urban studies. Although these digital methods improve efficiency, they also introduce challenges related to data accuracy, representativeness, and privacy concerns. For instance, social media data may overrepresent certain demographic groups, while mobile tracking relies on smartphone usage, which may exclude populations without access to such technology.

Advancements in computer vision and deep learning have further revolutionized pedestrian counting methods. Li et al. [15] and Lian et al. [16] applied deep learning to extract pedestrian flow data from video footage, allowing for automated, large-scale analysis of street vitality. Similarly, Liu and Ameijde [17] used deep learning to estimate pedestrian numbers from Street View Images. These approaches offer higher accuracy and scalability compared to traditional methods; however, they are still constrained by factors such as image resolution and the need for extensive training data. Despite these limitations, deep learning-based methods provide a more accurate and objective alternative to manual pedestrian counts. Moreover, unlike social media or mobile tracking, they reflect actual street usage, making them a more representative and unbiased measure of street vitality.

2.2 Factors Affecting Street Vitality

Several studies have explored the factors and elements contributing to street vitality, employing diverse methodologies and focusing on different urban contexts. Xu et al. [12] investigated the impact of street form, business types, and street accessibility on the vitality of nine streets in Nanjing City, China. For street form, the study identified interface continuity and the height-to-width ratio as key elements. Street business types were assessed through store density, function density, and the permeability of ground-floor interface. Finally, street accessibility was evaluated based on the number of entrances along the streets and the proximity to public transportation, residential areas, and large business facilities. Similarly, Li et al. [18] examined the impact of these variables on 1532 streets in Ding Shu City, China.

Yuan and Chen [19] examined how the transportation environment and built environment variables influence the vitality of 441 street segments in Shanghai’s high-density downtown area. Transportation-related variables included street connectivity, street length, entrance/exit density, proximity to public transit (e.g., subway and bus stations), bus stop density, and width of pedestrian-designated spaces. Built environment variables included store density, function density, permeability of ground-floor interface, and proximity to large functional facilities as key contributors to street vitality.

Li et al. [15] explored how width of pedestrian-designated spaces, visible greenery, street openness, permeability of ground-floor interface, and store density influence street vitality in a commercial complex in Osaka, Japan. Similarly, Lian et al. [16] examined the impact of these variables along with public seating and billboard density on street vitality in two commercial streets in China.

Zhou et al. [20] investigated the influence of various environmental factors on the vitality of pedestrian streets in Beijing, categorizing them as spatial street elements and climatic-physical factors. Spatial elements included street orientation, street height-to-width ratio, tree greenness volume, and tree spacing. Climatic factors encompassed temperature, relative humidity, wind speed, and physiologically equivalent temperature (PET).

Mu et al. [21] analyzed how public service elements, pedestrian interaction elements, building interface elements, and spatial perception elements contribute to the vitality of Central Street in Harbin, China. Public service elements included bench density (both formal and auxiliary benches), flower bed density, sanitation facility density, directional sign density (e.g., commercial maps), and the density of other service facilities such as vending machines and shared power banks. Pedestrian interaction elements encompassed the density of recessed areas, sculptures, and commercial interactive features (e.g., store mascots). Building interface elements focused on the permeability of ground-floor interfaces, density of commercial display elements (e.g., signage and neon signs), store density, and function density. Spatial perception elements included visible street greenery, the street height-to-width ratio, the width of pedestrian-designated spaces, street elevation differences, street openness, and interface continuity.

In addition to the previously discussed factors, Li et al. [22] highlighted the significance of street maintenance, particularly tidiness and pavement integrity, in enhancing street vitality. Xu and Ma [23] emphasized the role of street lighting in creating engaging public spaces that foster community interaction. Goel and Bhavsar [24] discussed the role of low noise levels in creating a calm and pleasant atmosphere, which can attract more people and encourage greater community engagement. Li et al. [25] noted that color richness can enhance the visual appeal of streets, making them more attractive and inviting, which may, in turn, increase foot traffic and social interactions.

Based on the reviewed literature, the factors influencing street vitality can be categorized into several key dimensions: street form, street accessibility, land use, commercial appeal, aesthetic and sensory appeal, public amenities, and microclimate. Table 1 provides a detailed classification of these factors, their potential impacts on street vitality, their methods of quantification, and the tools used for measurement.

3 MATERIALS AND METHODS

This study aims to explore the key factors influencing pedestrian street vitality in Downtown Cairo. To achieve this, the process followed three main steps: first, the study streets were selected; second, the identified factors were measured across the selected streets; and third, appropriate statistical methods were applied (see Figure 1). It is worth noting that the number of pedestrians was used in this study as the primary indicator of street vitality.

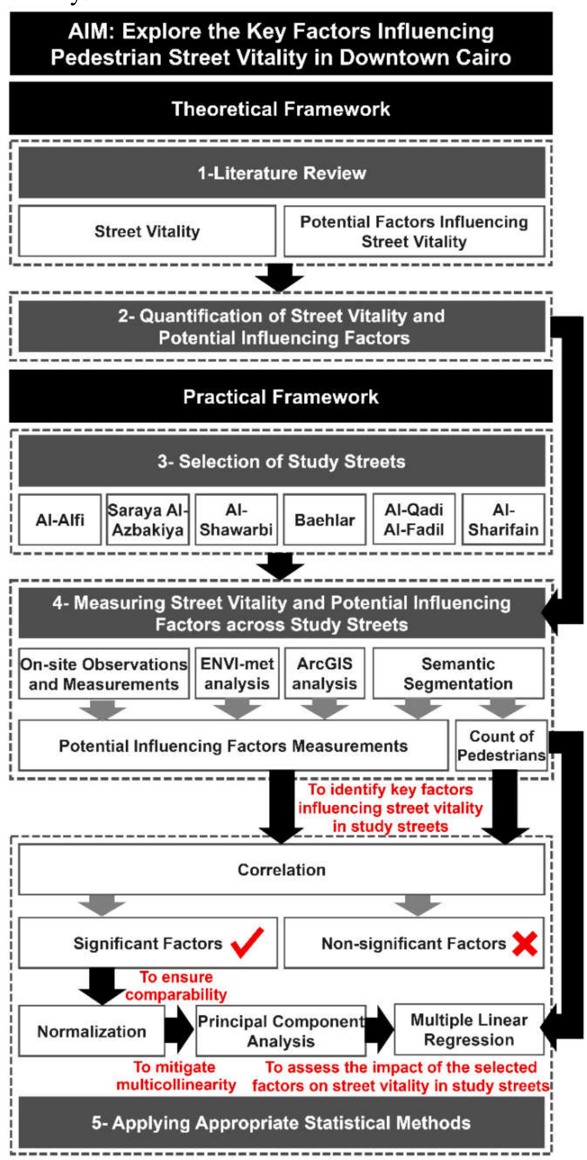

Figure 1: Research framework

Table 1. Classification of factors influencing street vitality, adopted from [12], [15], [16], [18]–[25]

	Key factors	Potential impact on street vitality	Methods of quantification	Tools
Street Form	Width of pedestrian-designated spaces	Wider spaces facilitate movement and support diverse pedestrian activities (e.g., walking, lingering, socializing), making streets more inviting.	Total surface area designated for pedestrian / Total length of street.	ArcGIS
	Street length	Longer streets can accommodate more functions, encouraging longer stays.	Total length of pedestrian designated area.	ArcGIS
	Width-to-Height Ratio	Street aspect ratio influences sunlight, airflow, and the perception of human scale, impacting the whole pedestrian experience.	Street width/ Average height of buildings along the street.	ArcGIS
	Street orientation	Street orientation affects sunlight exposure and wind, influencing thermal comfort.	Direction of the street in relation to the position of the sun.	ArcGIS
	Street elevation difference	Large elevation changes may hinder accessibility and reduce activity.	The difference in elevation between two parts of the street in a cross-section, which are typically connected by steps or curbstones.	On-site observations and measurements
	Pavement integrity	Pavement integrity affects pedestrian comfort and walkability, influencing the vitality and usability of streets.	(Total area designated for pedestrian - pedestrian areas in bad pavement condition)/ Total area designated for pedestrian.	On-site observations and measurements
	Interface continuity	Interface continuity can provide visual coherence but can become monotonous if it is excessively uniform.	Total buildings length along the street/ Total length of street.	ArcGIS
	Recessed areas density	Recessed areas create gathering spots but may lead to underused or unsafe areas if overused.	Number of recessed areas. Number of recessed areas/ Total length of street.	On-site observations and measurements
Street Accessibility	Street connectivity	Higher street connectivity, shorter distances to public transportation, and a greater density of stops and stations enhance accessibility and attract more users	Number of intersecting streets. Number of intersecting streets/ Total length of street.	ArcGIS
	Proximity to public transportation		Distance to the nearest metro stations and bus stops.	ArcGIS
	Public transportation stop density		Number of metro stations and bus stops within 200m of street.	ArcGIS
	Density of building entrances	Higher number of entrances increases access points, leading to greater foot traffic.	Number of building entrances on street. Number of building entrances on street/ Total length of street.	On-site observations and measurements
Land use	Store density	Increased store density can drive more frequent and varied pedestrian activity.	Number of operating stores, including specific store types known to attract people, alongside the total number of operating stores in the area. Number of operating stores/ Total length of street.	On-site observations and measurements
	Function density	Increased function density encourages continuous activity throughout the day.	Number of functional types within the street space. Number of functional types within the street space/ Total length of street.	ArcGIS
	Proximity to residential areas	Nearby homes increase local use and boost daytime activity.	Number of residential buildings within 200m.	ArcGIS
	Proximity to large functional facilities	Nearby facilities draw visitors, boosting surrounding streets vitality.	Number of large functional facilities (e.g. large commercial and educational facilities) within 200m.	ArcGIS
Commercial Appeal	Ground-floor interface permeability	High ground-floor interface permeability facilitates visual interaction and engagement.	(Length of open storefronts + (Length of transparent glass windows allowing direct visibility into the interior*0.75) + (Length of display windows with merchandise setups*0.5))/ Total length of buildings.	On-site observations and measurements
	Density of commercial display elements	Higher density of commercial display elements enhances storefront visibility and commercial engagement.	Number of commercial display elements. Number of commercial display elements/ Total length of street.	On-site observations and measurements

Category	Key factors	Potential impact on street vitality	Methods of quantification	Tools
	Commercial interactive elements density	Higher density of commercial interactive elements attracts a wider range of visitors and boosts commercial activity.	Number of commercial interactive elements. Number of commercial interactive elements/ Total length of street.	On-site observations and measurements
Aesthetic and Sensory Appeal	Visible greenery	Visible greenery enhances visual appeal and encourages lingering.	Total tree, plant, and grass pixels in street image/ Total pixels in the image.	Semantic segmentation
	Tree crown volume	Tree crown volume plays a crucial role in mitigating heat and improving thermal comfort.	Total tree crowns pixels in a street image/ Number of trees.	Semantic segmentation
	Tree spacing	Appropriate tree spacing can promote air circulation and shade, encouraging visitors to linger.	Average distance between trees within the street space.	On-site observations and measurements
	Street openness	Open views of the sky create a more welcoming environment.	Total sky pixels in street image/ Total pixels in the image.	Semantic Segmentation
	Sculptures density	Sculptures add visual appeal and reflect urban culture.	Number of sculptures. Number of sculptures/ Total length of street.	On-site observations and measurements
	Flower bed density	Higher flower bed density enhances street aesthetics and enriches the pedestrian experience.	Total flower bed pixels in a street image/ Total pixel in the image.	Semantic Segmentation
	Street tidiness	Tidiness enhances the visual appeal of street, making it cleaner and more inviting to pedestrians.	Total tidy street length/ Total length of street.	On-site observations and measurements
	Color richness	Color richness improves the street's visual environment, boosting attractiveness and encouraging pedestrian activity.	Number of visible distinct colors Number of visible distinct colors/ Total length of street.	On-site observations and measurements
	Noise level	Low and moderate noise levels create a calm and pleasant atmosphere, attracting more people and promoting social interaction and community engagement.	Measuring street sound levels in decibels (dB).	On-site observations and measurements
Public Amenities	Public formal bench density	Higher public bench density fosters social interaction and encourages longer stays.	Number of formal benches. Number of formal benches/ Total length of street.	On-site observations and measurements
	Public auxiliary bench density		Number of auxiliary benches. Number of auxiliary benches/ Total length of street.	On-site observations and measurements
	Sanitation facility density	Higher sanitation facility density improves cleanliness, comfort, and convenience	Number of sanitation facilities. Number of sanitation facilities/ Total length of street.	On-site observations and measurements
	Directional sign density	Effective directional signage supports navigation and improves accessibility.	Number of directional signs. Number of directional signs/ Total length of street.	On-site observations and measurements
	Street lighting density	Higher street lighting density improves safety and comfort, creating an inviting atmosphere for pedestrians.	Number of streetlights Number of streetlights/ Total length of street.	On-site observations and measurements
Microclimate	Temperature	Comfortable temperatures enhance activity and dwell time.	Temperature level of the air in the street.	Digital Anemometer
	Relative humidity	High humidity can discourage outdoor activity due to discomfort.	Actual water vapor content in the air to the maximum amount of water vapor that the air can hold at a given temperature.	Digital Anemometer
	Wind speed	Moderate wind speed enhances heat dissipation, reduces perceived temperature, and improves thermal comfort.	Speed of air movement in the street space.	Digital Anemometer
	Physiologically Equivalent Temperature	High PET reduces comfort, dwell time, and activity engagement.	The effect of atmospheric conditions on the human body.	ENVI-met

3.1 Study area

Downtown Cairo area features a network of approximately 162 passageways, varying in form, scale, and land use [18]. Within this network, some passageways primarily function as pedestrian streets, accommodating various activities and allowing little to no vehicular access. In this context, this study focuses on six pedestrian streets within two zones, as shown in Figure 2. These streets were selected due to variations in pedestrian flow, as well as differences in activity types and density. These variations will help identify the key factors that have the most significant impact on street vitality through statistical analysis. The selected streets are Al-Alfi, Saraya Al-Azbakiya, Al-Shawarbi, Baehlar, Al-Qadi Al-Fadil, and Al-Sharifain.

3.2 Data Collection and Measurement Methods

To measure the previously quantified factors within the selected streets, semantic segmentation, ArcGIS analysis, ENVI-met analysis, and on-site observations and measurements were utilized.

3.2.1 Semantic Segmentation

Semantic segmentation is a computer vision technique that classifies each pixel in an image into a specific class or object, such as sky, buildings, vegetation, and vehicles. With advancements in deep learning, this technique has become more precise and efficient. In this study, the Deeplab V3 model framework was used for semantic segmentation and analysis of street-level imagery to identify number of pedestrians, visible greenery, tree crown volume, and street openness. Jupyter Notebook was used to process the images, generate segmented outputs, and compute relevant statistical data, such as pixel counts for each category.

To acquire street-level imagery, three visits were conducted to the selected streets at different times of the day and on different days of the week. These visits took place on December 26, 28, and 30, 2024. During each visit, pedestrian counts were observed. Images were captured on December 30, the day with the highest observed pedestrian count. At each street, images were captured from four perspectives: left and right along the street and at each entrance. A mobile phone, held at eye level to maintain a horizontal line of sight, was used to simulate a pedestrian's perspective.

The model's performance was validated using a sample set of the acquired images to ensure accuracy. A qualitative assessment was conducted by visually inspecting the segmented images. This involved overlaying the predicted segmentation masks onto the original street images to evaluate how well the model distinguishes between different urban elements. The validation results indicated that the model performed well, accurately segmenting key urban elements relevant to this study (i.e., persons, greenery, and sky) with minimal errors (see Figure 3).

Figure 2: Selected Study Streets

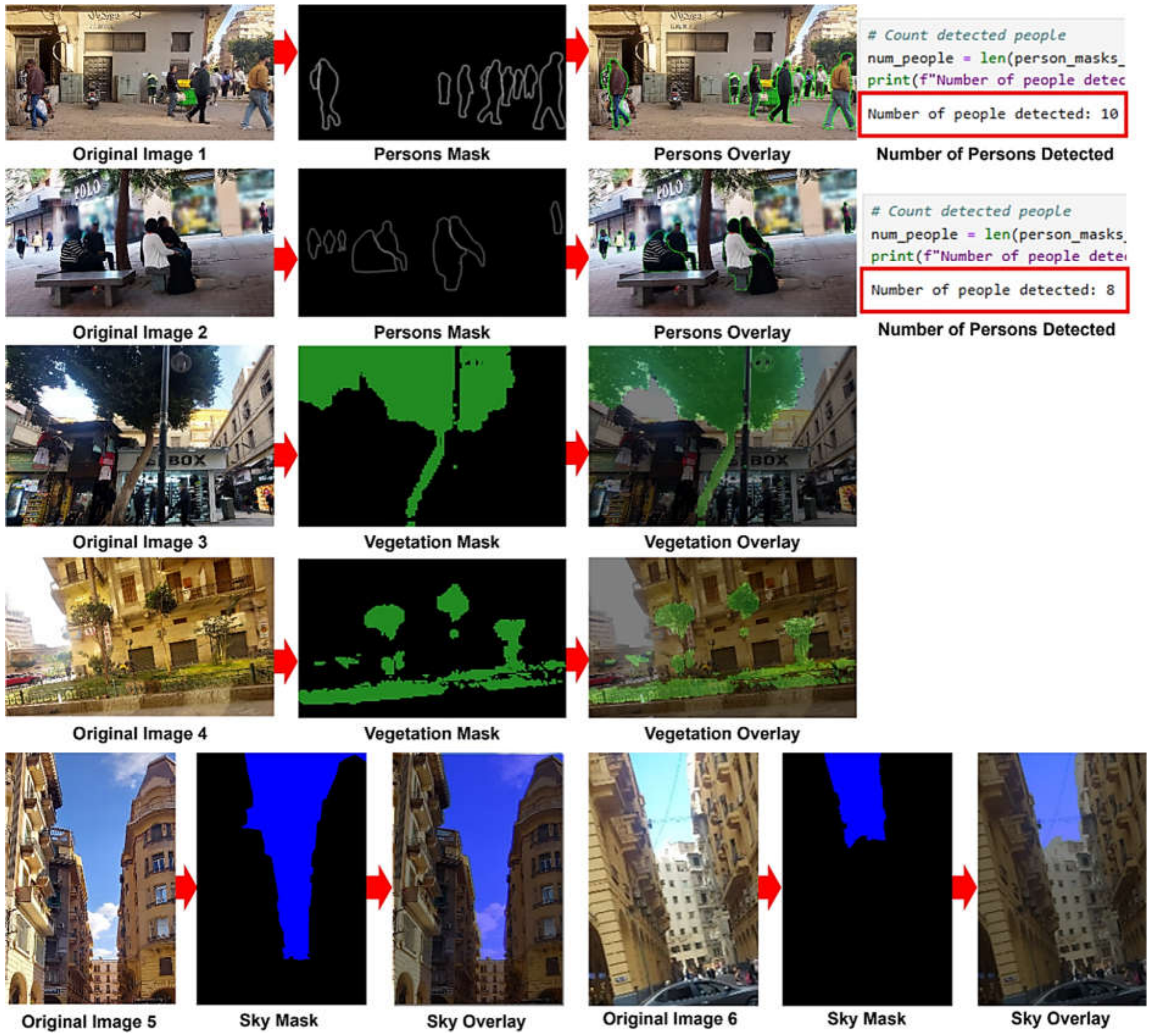

Figure 3: Validation of used segment segmentation models

3.2.2 ArcGIS analysis

Street length, pedestrian-designated spaces, average height of buildings along each street, total buildings length along each street, number of intersecting streets, distance to the nearest metro stations and bus stops, number of metro stations and bus stops within 200 meters, number of functional types, and number of residential buildings within 200 meters were calculated using ArcGIS based on shapefile data obtained from the Geofabrik website, as well as geographic maps from the Cairo Governorate website and the Cairo Lab for Urban Studies, Training, and Environmental Research (CLUSTER) website.

3.2.3 ENVI-met analysis

Due to the unavailability of a digital anemometer, temperature, relative humidity, wind speed, along with Physiologically Equivalent Temperature (PET) were simulated using ENVI-met software, with the simulation set for December 30, 2024.

3.2.4 On-site observations and measurements

On-site observations were conducted along the selected streets to document elements that may not be fully captured through image-based analysis or maps. These elements include street elevation differences, pavement integrity, recessed areas, entrances of residential properties, store density, ground-floor interface permeability, commercial display elements, commercial interactive elements, tree spacing, sculpture density, street tidiness, the presence of distinct colors, public benches (both formal and auxiliary), sanitation facilities, directional signs, and street lighting.

It is worth noting that measurements related to the densities of recessed areas, commercial interactive elements, sculptures, flower beds, sanitation facilities, and directional signs were excluded from this study due to their absence on the studied streets. Pavement integrity and street tidiness were also excluded as all streets exhibited good surface conditions and were consistently clean, with little variation observed.

Additionally, on-site noise measurements were taken using the "Sound Meter & Noise Detector" smartphone application, which quantifies sound levels in decibels (dB).

Examples of measurements across study streets are presented in Figure 4.

3.3 Statistical methods

To identify key factors influencing pedestrian street vitality in Downtown Cairo, Pearson correlation analysis was conducted between the number of pedestrians and potential influencing factors using SPSS 27.0. Factors with statistically significant correlations ($p < 0.05$) were selected for further analysis. Since these selected factors had different units (e.g., lengths and counts), they were normalized to ensure comparability. To address multicollinearity, Principal Component Analysis (PCA) was performed, transforming the significant factors into uncorrelated components. Finally, multiple linear regression was conducted, using the extracted PCA component(s) as independent variable(s) and number of pedestrians as the dependent variable, to assess their impact on pedestrian street vitality.

4 RESULTS AND DISCUSSION

According to the correlation analysis results (Table 2), several factors are positively correlated with the number of pedestrians in the selected streets. These include width of pedestrian designated spaces, street length, width to height ratio, interface continuity, number of intersecting streets, public transportation stop density, number of building entrances, number and density of operating restaurants and cafés, number and density of operating mini markets, number and density of operating clothing stores, density of operating clothing stores, number and density of total operating stores, number of functions within street, proximity to residential areas, proximity to large functional facilities, ground-floor interface permeability, number and density of commercial display elements, visible greenery along streets and from entrances, number and density of visible distinct colors, noise level, number and density of formal benches, number and density of streetlights, temperature, and PET.

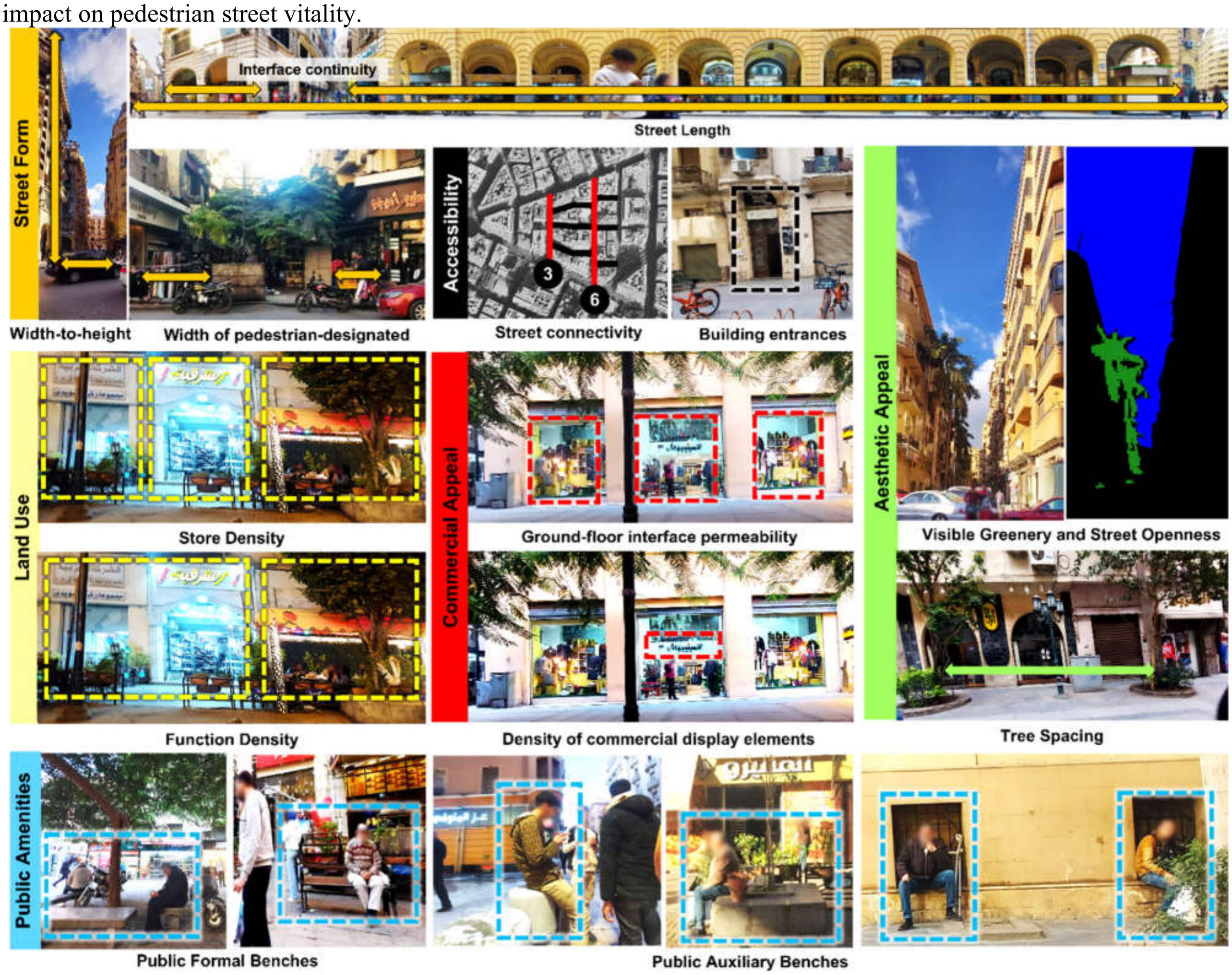

Figure 4: Examples of measurements across study streets

Table 2. Correlation analysis results

	Factors		Pearson (*R*)	Sig. (*P*)	Degree of correlation
Street Form	**Width of pedestrian-designated spaces**		**0.839***	**0.037**	**Significant**
	Street length		**0.894***	**0.016**	**Significant**
	Width to height ratio		0.580	0.228	Not Significant
	Street orientation		-0.534	0.275	Not Significant
	Interface continuity		0.532	0.278	Not Significant
Street Accessibility	Street Connectivity	Number of intersecting streets	0.517	0.294	Not Significant
		Density of intersecting streets	-0.092	0.863	Not Significant
	Distance to public transportation stops		-0.114	0.830	Not Significant
	Public transportation stop density		0.394	0.440	Not Significant
	Density of entrances	Number of building entrances.	0.249	0.635	Not Significant
		Density of building entrances.	-0.445	0.377	Not Significant
Land use	Store density	Number of operating restaurants and cafés.	0.414	0.377	Not Significant
		Density of operating restaurants and cafés.	0.369	0.472	Not Significant
		Number of operating mini markets	**0.918****	**0.010**	**High Significant**
		Density of operating mini markets	0.802	0.055	Not Significant
		Number of operating clothing stores	0.564	0.243	Not Significant
		Density of operating clothing stores	0.255	0.626	Not Significant
		Number of total operating stores	**0.813***	**0.049**	**Significant**
		Density of operating stores	0.554	0.254	Not Significant
	Function density	**Number of functions within street**	**0.815***	**0.048**	**Significant**
		Density of functions	-0.745	0.089	Not Significant
	Proximity to residential areas		**0.815***	**0.048**	**Significant**
	Proximity to large functional facilities		0.464	0.354	Not Significant
Commercial Appeal	Ground-floor interface permeability		0.462	0.356	Not Significant
	Density of commercial display elements	**Number of commercial display elements**	**0.886***	**0.019**	**Significant**
		Density of commercial display elements	0.621	0.189	Not Significant
Aesthetic and Sensory Appeal	Visible greenery	Visible greenery along street	0.488	0.327	Not Significant
		Visible greenery from entrances	0.571	0.237	Not Significant
	Tree crown volume		0.787	0.063	Not Significant
	Tree spacing		-0.360	0.484	Not Significant
	Street openness		-0.678	0.139	Not Significant
	Color richness	Number of visible distinct colors	0.686	0.133	Not Significant
		Density of visible distinct colors	0.154	0.771	Not Significant
	Noise level		0.750	0.086	Not Significant
Public Amenities	Public formal bench density	Number of formal benches	0.673	0.143	Not Significant
		Density of formal benches	0.681	0.136	Not Significant
	Public auxiliary bench density	Number of auxiliary benches	-0.150	0.777	Not Significant
		Density of auxiliary benches	-0.345	0.503	Not Significant
	Street lighting density	Number of streetlights	0.431	0.394	Not Significant
		Density of streetlights	0.205	0.697	Not Significant
Micro-climate	Temperature		0.126	0.812	Not Significant
	Relative humidity		-0.199	0.705	Not Significant
	Wind speed		-0.051	0.924	Not Significant
	PET		0.043	0.936	Not Significant

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed).

Conversely, certain factors show a negative correlation with the number of pedestrians in the selected streets. These include street orientation, density of intersecting streets, distance to public transportation stops, density of building entrances, density of functions within street, tree spacing, street openness, number and density of auxiliary benches, relative humidity, and wind speed.

However, among all these variables, only the width of pedestrian designated spaces, street length, number of operating mini markets, total number of operating stores, number of functions within street, proximity to residential areas, and number of commercial display elements were found to have a statistically significant correlation with pedestrian count. These factors can be considered key determinants of pedestrian street vitality in Downtown Cairo.

To further assess their impact and mitigate multicollinearity, the selected factors were normalized and subjected to Principal Component Analysis (PCA). The PCA identified a single dominant component that explained 79.80% of the total variance in the dataset (Table 3) and captured 69% to 91% of each factor's variance (Table 4). These high percentages indicate that the extracted component effectively retains most of the information from the original factors. Additionally, all factors exhibited strong loadings on this component, ranging from 0.830 to 0.955, underscoring their significant contributions (Table 4). Since no variable demonstrated weak loadings (typically below 0.4), the component's robustness in representing the dataset is further validated. Thus, this component serves as a comprehensive measure of the combined influence of the original variables.

Linear regression was then applied, using the extracted PCA component as the independent variable. Results showed that the model's correlation coefficient (R) was 95.5%, indicating a strong linear relationship between street vitality and the extracted component. The R-squared and adjusted R-squared values were 0.913 and 0.891, respectively (Table 5). This suggests that variations in street vitality can be largely explained by changes in the extracted component, which represents the selected factors.

Finally, the significance test (F-test) was performed for the multiple linear regression model. The F-test is typically used to determine whether the independent variables have a significant overall impact on the dependent variable. As illustrated in Table 6, the value of F is 41.840 and the Sig. value is less than 0.05, indicating that the extracted component, which represents the significant factors, has a strong influence on street vitality and the overall relationship is statistically significant.

In this study, the t-test for the linear regression model was omitted because the analysis involved only one independent variable, the PCA-extracted component. When a regression model includes a single predictor, the F-test and t-test produce equivalent results, as both assess the significance of the independent variable's contribution to the dependent variable. Since the F-test confirmed that the extracted component significantly influences street vitality ($F = 41.840$, $p < 0.05$), conducting a separate t-test would be redundant.

Based on the previous results, promoting high vitality in Downtown Cairo's future pedestrianized streets may benefit from a strategic approach to both street selection and activity planning. In terms of street selection, longer streets located near denser residential areas, with wider pedestrian spaces, could be prioritized for pedestrianization over shorter, narrower streets situated farther from residential zones. These streets tend to attract more foot traffic, not only because they can accommodate diverse activities while ensuring smooth pedestrian movement, but also because nearby residential buildings generate consistent pedestrian flow. This has the potential to foster more engaging and accessible streets.

Regarding activity planning, expanding commercial options, increasing functional diversity, and incorporating commercial display elements are likely to support the development of vibrant pedestrianized streets. These strategies can help attract a diverse range of visitors, support both day and night activities, and enhance street appeal and social interaction. Collectively, this may enhance pedestrian engagement and contribute to transforming streets into lively, dynamic urban spaces.

Table 3. Total variance explained using PCA

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	**5.586**	**79.796**	**79.796**	**5.586**	**79.796**	**79.796**
2	.707	10.101	89.898			
3	.405	5.785	95.683			
4	.277	3.960	99.642			
5	.025	.358	100.000			
6	9.369 E-16	1.338 E-14	100.000			
7	6.231 E-17	8.901 E-16	100.000			

Table 4. PCA results of original variables

	Communalities Extraction	Component 1
Width of pedestrian designated spaces	0.689	0.830
Street length	0.912	0.955
No. of operating mini markets	0.747	0.864
No. of total operating stores	0.694	0.833
No. of functions within street	0.877	0.937
Proximity to residential areas	0.865	0.930
No. of commercial display elements	0.801	0.895

Table 5. Linear regression model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**0.955a**	**0.913**	**0.891**	22.00463

a. Predictors: (Constant), Extracted component

Table 6. Linear regression ANOVA[a] test result

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20259.184	1	20259.184	**41.840**	**.003[b]**
	Residual	1936.816	4	484.204		
	Total	22196.000	5			

a. Dependent Variable: Number of pedestrians
b. Predictors: (Constant), Extracted component

It is important to note that high-vitality streets with heavy pedestrian flow do not necessarily provide a good perceptual experience. Congested and noisy streets can create discomfort and sensory overload, making them less enjoyable for pedestrians. Therefore, maintaining a balance between vitality and comfort is crucial for successful pedestrianized street design.

5 CONCLUSION

This study investigated the key factors influencing pedestrian street vitality in Downtown Cairo to guide future planning and keep pedestrianized streets safe, attractive, and well-utilized. A literature review was conducted on street vitality and its influencing factors, which were then quantified. Six study streets were selected: Al-Alfi, Saraya Al-Azbakiya, Al-Shawarbi, Baehlar, Al-Qadi Al-Fadil, and Al-Sharifain. The identified factors were measured across these streets using semantic segmentation, ArcGIS, ENVI-met, and on-site observations and measurements. Pedestrian count was selected as the key indicator of street vitality. To analyze the relationship between street vitality and its influencing factors, Pearson correlation analysis was performed, identifying statistically significant factors ($p < 0.05$). These factors were then normalized and subjected to Principal Component Analysis (PCA) to transform them into uncorrelated components.

Finally, multiple linear regression was conducted using the extracted PCA component as an independent variable to assess its impact on street vitality. The results indicate that the width of pedestrian-designated spaces, street length, number of operating mini markets, total number of operating stores, diversity of street functions, proximity to residential areas, and number of commercial display elements all have a strong positive and statistically significant influence on street vitality. Consequently, to ensure high vitality in Downtown Cairo future pedestrianized streets, a strategic approach is recommended for both street selection and activity planning. Future planning could prioritize longer streets located near denser residential areas, with wider pedestrian spaces for pedestrianization while also expanding commercial options, diversifying street functions, and incorporating commercial display elements to create vibrant and engaging streets.

However, this study has several limitations. Firstly, the research is constrained by a limited sample size of only six streets. Expanding the sample size to more streets would likely enhance the robustness of the results and provide broader and more applicable conclusions. Secondly, the selected streets have specific characteristics, which may limit the statistical analysis of some factors influencing street vitality. These factors include densities of recessed areas, commercial interactive elements, sculptures, flower beds, sanitation facilities, and directional signs. The exclusion of these factors could potentially introduce bias into the analysis, potentially affecting the accuracy of the findings. Future research could consider incorporating these factors when selecting streets to explore a wider range of influences on street vitality. Additionally, the study relies solely on the number of pedestrians as an indicator of street vitality. While this is a commonly used metric, it does not differentiate between active engagement and passive presence. Thus, further analysis incorporating additional indicators, such as duration of stay, pedestrian activities, and social interactions, might provide a more comprehensive understanding of street vitality.

Ethics information

In this research, pedestrian photos were captured solely for analytical purposes while ensuring strict adherence to ethical guidelines. The images were used exclusively for studying street vitality and pedestrian movement, with no intent to identify individuals. To protect privacy, all images were anonymized, and no personal or sensitive information was recorded. Additionally, data collection was conducted in public spaces where there is no reasonable expectation of privacy, aligning with ethical research standards.

Acknowledgments

The author would like to thank the reviewers for their constructive and thoughtful comments and suggestions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Funding

The authors declare that they hadn't received any funding.

6 REFERENCES

[1] Ahram Online, “Egypt to transform government buildings in Downtown Cairo into luxury hotels,” *Ahram Online*, Dec. 27, 2024. [Online]. Available: https://english.ahram.org.eg/NewsContent/1/1235/537638/Egypt/Urban--Transport/Egypt-to-transform-government-buildings-in-Downtow.aspx

[2] K. A. Robertson, “Pedestrianization Strategies for Downtown Planners: Skywalks Versus Pedestrian Malls,” *J. Am. Plan. Assoc.*, vol. 59, no. 3, pp. 361–370, Jun. 1993, doi: 10.1080/01944369308975887.

[3] P. Cozens and T. Love, “Manipulating Permeability as a Process for Controlling Crime: Balancing Security and Sustainability in Local Contexts,” *Built Environ.*, vol. 35, no. 3, pp. 346–365, Mar.

2009, doi: 10.2148/benv.35.3.346.

[4] L. Hopkinson, B. Hiblin, M. Wedderburn, K. Chatterjee, S. Cairns, and Michael Frearson, "The Pedestrian Pound (3rd edition)," 2024. [Online]. Available: https://www.livingstreets.org.uk/media/y4ijyp1n/pedestrian_pound_3rd-edition.pdf

[5] J. Jacobs, *The Death and Life of Great American Cities*. New York: Random House, 1961. [Online]. Available: https://www.petkovstudio.com/bg/wp-content/uploads/2017/03/The-Death-and-Life-of-Great-American-Cities_Jane-Jacobs-Complete-book.pdf

[6] O. Newman, *Defensible Space: Crime Prevention Through Urban Design*. New York: The Macmillan Company, 1972. [Online]. Available: https://unbrokenwindows.queensmuseum.org/index/defensible-space-crime-prevention-through-urban-design-chapter-1-defensible-space

[7] L. E. Cohen and M. Felson, "Social Change and Crime Rate Trends: A Routine Activity Approach," *Am. Sociol. Rev.*, vol. 44, no. 4, 1979, doi: https://doi.org/10.2307/2094589.

[8] J. Gehl and B. Svarre, *How to Study Public Life*. London: Island Press, 2013.

[9] E. Klinenberg, *Palaces for the People: How Social Infrastructure Can Help Fight Inequality, Polarization, and the Decline of Civic Life*. New York: Crown Publishing Group, 2018.

[10] M. Liu, Y. Jiang, and J. He, "Quantitative Evaluation on Street Vitality: A Case Study of Zhoujiadu Community in Shanghai," *Sustainability*, vol. 13, no. 6. 2021. doi: 10.3390/su13063027.

[11] A. March, Y. Rijal, S. Wilkinson, and E. Firidin Özgür, "Measuring Building Adaptability and Street Vitality," *Plan. Pract. Res.*, vol. 27, no. 5, pp. 531–552, Oct. 2012, doi: 10.1080/02697459.2012.715813.

[12] X. Xu, X. Xu, P. Guan, Y. Ren, W. Wang, and N. Xu, "The Cause and Evolution of Urban Street Vitality under the Time Dimension: Nine Cases of Streets in Nanjing City, China," *Sustainability*, vol. 10, no. 8. 2018. doi: 10.3390/su10082797.

[13] W. Wu, X. Niu, and M. Li, "Influence of Built Environment on Street Vitality: A Case Study of West Nanjing Road in Shanghai Based on Mobile Location Data," *Sustainability*, vol. 13, no. 4. 2021. doi: 10.3390/su13041840.

[14] A. Abdel-Rasoul, "Visualizing vital public spaces in Cairo using Twitter API," *J. Archit. Arts, Humanist. Sci.*, vol. 10, no. 49, pp. 148–165, 2025, doi: 10.21608/mjaf.2023.209988.3101.

[15] Y. Li, N. Yabuki, and T. Fukuda, "Exploring the association between street built environment and street vitality using deep learning methods," *Sustain. Cities Soc.*, vol. 79, p. 103656, 2022, doi: 10.1016/j.scs.2021.103656.

[16] H. Lian, X. Li, W. Zhou, J. Zhang, and H. Li, "Pedestrian vitality characteristics in pedestrianized commercial streets-considering temporal, spatial, and built environment factors," *Front. Archit. Res.*, vol. In Press, 2024, doi: 10.1016/j.foar.2024.10.006.

[17] X. Liu and J. Van Ameijde, "Data-driven Research on Street Environmental Qualities and Vitality Using GIS Mapping and Machine Learning, a Case Study of Ma On Shan, Hong Kong," in *Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA)*, 2022, pp. 485–494.

[18] J. LI, Z. SONG, J. WEN, C. CAI, and P. TANG, "Exploring Nonlinear Relationship between Built Environment and Street Vitality Using Machine Learning: A Case Study of Ding Shu, China," in *Proceedings of the 29th International Conference of the Association for ComputerAided Architectural Design Research in Asia (CAADRIA)*, 2024. doi: 10.52842/conf.caadria.2024.2.375.

[19] M. Yuan and Y. Chen, "Analysis of Factors Influencing Street Vitality in High-Density Residential Areas Based on Multi-source Data: A Case Study of Shanghai," *Int. J. High-Rise Build.*, vol. 10, no. 1, pp. 1–8, 2021, doi: 10.21022/IJHRB.2021.10.1.1.

[20] W. Zhou, J. Zhang, X. Li, F. Guo, and P. Zhu, "Influence of Environmental Factors on Pedestrian Summer Vitality in Urban Pedestrian Streets in Cold Regions Guided by Thermal Comfort: A Case Study of Sanlitun—Beijing, China," *Sustainability*, vol. 16, no. 23. 2024. doi: 10.3390/su162310419.

[21] X. Mu, L. Mu, and J. Zhang, "The Impact of Street Elements on Pedestrian Stopping Behavior in Commercial Pedestrian Streets from the Perspective of Commercial Vitality," *Sustainability*, vol. 16, no. 17. 2024. doi: 10.3390/su16177727.

[22] S. Li, Y. Ye, H. Chen, Y. Yang, Y. Huang, and Z. Wu, "Vitality Analysis and Improvement of Micro Urban Spaces in Cold Regions," *Int. Rev. Spat. Plan. Sustain. Dev.*, vol. 12, no. 3, pp. 95–117, 2024, doi: 10.14246/irspsd.12.3_95.

[23] Y. Xu and X. Ma, "Assessing Urban Street Vitality Through Visual and Auditory Perception: A case study of historic urban area in Guangzhou, China," *Int. Rev. Spat. Plan. Sustain. Dev.*, vol. 12, no. 4, pp. 57–76, 2024, doi: 10.14246/irspsd.12.4_57.

[24] P. Goel and F. Bhavsar, "Evaluating the Vitality of an Indian Market Street: The Case of Chandni Chowk, Delhi," in *Future is Urban: Livability, Resilience & Resource Conservation*, Routledge, Taylor & Francis Group, 2024.

[25] X. Li, B. Li, and Y. Su, "Spatial Heterogeneity of Built Environment Perception's Impact on Street Vitality: A Multi-Level Interpretative Framework Based on MGWR-SHAP," *Preprints*, 2025, doi: 10.20944/preprints202502.2100.v1.