

Modeling Pedestrian Behavior in Linear Public Spaces: The Case of the Nile Waterfront "Mamsha Ahl Masr"

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Received October 11, 2024; Revised March 2, 2025; Accepted March 20, 2025

Cite This Paper in the Following Citation Styles

(a): [1] Aida Nayer, Samar Awad Abdelhamed Soliman, Dalia Abdelfattah , "Modeling Pedestrian Behavior in Linear Public Spaces: The Case of the Nile Waterfront 'Mamsha Ahl Masr'," *Civil Engineering and Architecture*, Vol. 13, No. 3, pp. 1723 - 1740, 2025. DOI: 10.13189/cea.2025.130321.

(b): Aida Nayer, Samar Awad Abdelhamed Soliman, Dalia Abdelfattah (2025). *Modeling Pedestrian Behavior in Linear Public Spaces: The Case of the Nile Waterfront 'Mamsha Ahl Masr'*. *Civil Engineering and Architecture*, 13(3), 1723 - 1740. DOI: 10.13189/cea.2025.130321.

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Abstract The design of urban spaces that foster sustainable practices along the waterfront requires new analytical and structural approaches to promote spatial planning processes. This research discusses the relationship between the configuration of riverbanks as linear urban spaces and the public interest by studying the appropriation of pedestrian behavior. This paper adopts a multi-method approach to investigate pedestrian movement and interactions in linear urban spaces. By combining automated trajectory analysis with environmental mapping, behavioral observation, and user interviews, this approach enables to capture qualitative insights into user experience, and perceptions of safety and comfort. The study aims to identify factors that influence the visitors flow patterns, evaluate the impact of design features, and uncover safety concerns. The model incorporates spatial analysis for the stipulated urban features, and testing visitors' alternatives for the new transformation of the Nile riverfront project. The new pedestrian promenade known as "Mamsha-Ahl Masr" (the walk of Egypt's citizens), incorporates several transformations of the river landscape which aims to improve the quality of life for the first completed phase and further extensions are taking place consecutively. However, the quantitative understanding of population flows expedites specific procedures on the urban scale to showcase people's interactions. Therefore, the research deploys a multi-agent behavior simulation technology to demonstrate the interaction between individuals and the

linear environment. The research represents empirical data synthesizing variables that affect walkability models related to visitors' attractiveness towards diverse activity preferences, clustering, and visiting frequency. Finally, the qualitative comparison and quantitative correlation analysis are combined to enhance the understanding of the spatial design features affecting visitors' experiences while studying the potential behavior simulation model. By combining these analyses, we can identify areas for improvement and optimize the promenade's design for a better pedestrian experience. The research explores the various scenarios for pedestrian flow tracking by explicitly simulating activities and therefore enhancing the aspects of social cohesion. The research concludes by presenting relevant criteria required for optimizing pedestrian-friendly experience in linear urban areas as a comprehensive approach that promotes walkability, safety, and social interaction in cities.

Keywords Pedestrian Behavior, Spatial Design, Modelling, Urban Dynamics, Walkability, Riverfront

1. Introduction

Waterfronts are dynamic urban spaces that offer a special combination of leisure, recreation, and natural connection, with significant potential to promote

sustainable practices within cities as indicated by the UN-Habitat in 2015 [1]. Given the ambition of cities to enhance livability, the design of public spaces for pedestrian activity becomes paramount. Sustainable public areas not only enhance social interaction and improve physical and mental well-being but also reduce reliance on private vehicles, thereby enhancing a city's overall environmental health. Unfortunately, traditional approaches to waterfront spatial planning often fall short of fully realizing these benefits. The movement patterns of pedestrians are complex and influenced by various factors, including the needs of users, accessibility, and design elements according to Sun, C. et al.[2]. This research examines pedestrian behavior in linear urban spaces, focusing on the Nile Waterfront project "Mamsha-Ahl Masr" as a case study. The conceptual framework integrates spatial analysis and behavioral modeling to understand the dynamic interplay between physical design, user experience, and social interactions in waterfront spaces. New methods that take into account the dynamic character of pedestrian behavior that go beyond the static design solutions are required to genuinely construct vibrant urban spaces along waterfronts. Analysis of pedestrian behavior is essential to support the design decisions that encourage social interaction, safety, and walkability [3]. It is critical to comprehend human movement patterns and interactions in these areas in order to define their spatial dynamics. By examining these movement patterns, urban spaces can be designed to become aesthetically pleasing, in addition to naturally functional, fostering social interaction and a sense of community [4]. In order to create standards for maximizing pedestrian-friendly experiences, the study intends to determine the elements affecting visitor flow patterns, assess the influence of design elements, and reveal safety issues. It tackles the deficiency of dynamic, data-driven methods in conventional waterfront planning, which frequently fail to capture pedestrian behavior complexities. Successful development requires a deep understanding of how people interact with these linear urban environments [5]. The study uses a multi-method approach that includes user interviews, behavioral observation, environmental mapping, and automated trajectory analysis. By combining these methods, areas for improvement can be identified and promenade's design optimized for a better pedestrian experience. Additionally, it makes use of multi-agent behavior simulation technologies for virtual situation preview and multi-plan comparison. Important conclusions emphasize how spatial components influence visitors' experiences and offer standards for improving urban design. With differences in density and activity levels connected to facilities and design elements, the study identifies clear pedestrian behavior patterns along the promenade. According to user perceptions, social connection, comfort, and safety are important components of overall satisfaction. By incorporating a variety of analytical techniques into the

conceptual framework, this study offers insightful information for planning and overseeing waterfront areas that satisfy the demands of urban communities.

2. Methodology

2.1. Research Aim

The research discusses the relationship between the configuration of riverbanks as linear urban spaces and the public interest by studying the appropriation of pedestrian behavior. Understanding pedestrian behavior is vital for defining spatial dynamics in public spaces. The research explores this thematic approach in detail and focuses on the Nile Waterfront, which represents a prime example of a linear urban space with a lot of potential. By using pedestrian behavior modeling approach as a multi-agent simulation technology to gain a deeper understanding of how people utilize this space and suggest design solutions that improve both its functionality and overall user experience [6]. With an emphasis on linear urban spaces as riverfronts, the research examines the literature review regarding pedestrian behavior modeling. It emphasizes the value of using a multi-method approach to demonstrate quantitative and qualitative data on pedestrian movement and experience.

2.2. Research Methodology

This paper uses a multi-method approach to investigate pedestrian movement and interactions in linear urban spaces, and combines automated trajectory analysis with environmental mapping, behavioral observation, and user interviews, to capture qualitative insights into user experiences, and perceptions of safety and comfort. The study aims to identify factors influencing flow patterns, evaluate the impact of design features, and uncover safety concerns. The model incorporates spatial analysis for the virtual elements and testing visitors' alternatives.

The study examines pedestrian interactions in an urban riverfront setting using multi-agent behavior simulation technologies. This method utilizes the quantitative understanding of population flows and the interaction between individuals and the environment, for multi-plan comparison and virtual situation preview, under the influence of complex environmental space elements in the urban riverfront. The research represents empirical data synthesizing variables affecting walkability models related to visitors' attractiveness towards diverse activity preferences.

2.3. Research Limitations: Case Study Selection

The "Mamsha Ahl Masr" project representing a linear public space is chosen as a case study for further assessment, due to its great impact on the urban

development, and economic growth of Cairo's waterfront. It has significant importance as a prime example of a comprehensive approach to urban regeneration since it combines functional infrastructure upgrades with aesthetically pleasing additions, by transforming the site into a pedestrian-friendly promenade. The public realm is improved and community involvement and social cohesiveness are promoted by the combination of green areas and cultural facilities like performance stages and concert venues. The project promotes tourism and start-up businesses by stimulating vibrant commercial zones. The "Mamsha Ahl Masr" project is considered one of the largest urban development initiatives in Cairo with multiple phases running according to a defined substantial plan. The project offers a comprehensive strategy of accommodating urban, environmental, sustainable, and economic aspects, in addition to intangible values as aesthetics, sense of place and user-friendly ambiance within the rapidly growing metropolitan city of Cairo. The selected area of study represents a pilot research as part of phase I completion, and results can be simulated for further extensions on both banks along the Nile River in Cairo in the following project phases. However, limitations can be encountered, as the case study focuses on Phase I, this might not fully represent the project's long-term impacts or challenges in later phases.

3. Waterfronts as Linear Urban Spaces

The design of vibrant and sustainable public spaces along waterfronts needs to be guided by analytical and structural approaches in order to create a successful spatial planning [7], understanding the relationship between the river waterfronts as linear urban spaces and the public's ownership of the space from the perspective of pedestrian behavior [8]. To fully understand these spaces' spatial dynamics and realize their potential for encouraging social interaction, encouraging physical activity, and improving a city's overall environmental health, it is imperative to understand how people move through and interact with them [9]. The research tackles the pedestrian behavior modeling in linear public spaces, focusing on methodologies and factors influencing pedestrian movement patterns [6]. It highlights the importance of understanding these patterns for optimizing the design of linear public spaces like the Nile Waterfront project, with a specific focus on the "Mamsha-Ahl Masr", (the walk of Egypt's citizens), as a case study representing the new transformation of the Nile riverfront project, the new pedestrian promenade as a sign for the transformation of the river landscape that aims to improve the quality of life and further expansion projects to revive green corridors and open areas across the densified areas of Cairo.

Furthermore, a growing volume of scholarly literature

addresses the variables affecting pedestrian behavior in linear open spaces. Two primary classifications can be employed to assemble these factors: design features and social interaction, as a challenging aspect of defining the physical configuration of linear public spaces.

3.1. Design Features

Research shows that parameters including path width, street furniture, and landscaping may impact pedestrian flow patterns and walking speeds. Wide paths, trees providing shade, and plenty of seats all seem to promote social interaction and pedestrian activity in public areas [5]. Conversely, narrow walkways, difficult surfaces, and little seats may discourage people.

3.2. Social Interaction

Social interaction plays a significant role in shaping pedestrian behavior [3]. Studies show that in order to communicate with other people, pedestrians frequently modify their walking pace and path to interact with others [10]. Plazas with seating and performance areas are examples of public areas that encourage social interaction and can draw more people and enhance the overall user experience [11].

3.3. Theoretical Representation of River Waterfronts as Linear Urban Spaces

History has witnessed a great evolution in the relationship of the river waterfronts. They were always considered as transportation arteries, where the early settlements were laid out. However, within the 20th and 21st centuries, a major shift was perceived towards the new perspective of interpreting rivers as linear urban spaces [9].

3.3.1. Historical Background and Timeline Representation

The early historical human settlements of ancient civilizations were developed around the rivers as a source of fresh water. Rivers played a crucial role in establishing cities. Settlements often clustered around natural harbors and fords [12]. The river Nile and Tigris-Euphrates are among the earliest to adopt the idea. Along their banks, religious events and trade took place.

During the Middle Ages and Renaissance, European cities grew up beside great rivers. Riverbanks developed into thriving sites for trade, transit, and cross-cultural interaction. Along the rivers, cities frequently developed naturally, with ports promoting trade and social interaction using riverfronts as urban places [13]. The riverfront witnessed massive transformations throughout the Industrial Revolution. Early factories were established by rivers, and waterfronts developed into industrial areas with ports, factories, and warehouses, which frequently led to pollution and a deterioration of public areas [14].

3.3.2. Modernised Perspective for Riverfronts in 20th Century

Riverfront development was influenced in the early 20th century by a Shift in Perspective: The early 20th century stated dysconnectivity between cities and their rivers. Pollution and industrial decline led to a negative perception of waterfronts. However, visionary thinkers like Ebenezer Howard, with his concept of "Garden Cities," began advocating for incorporating green spaces and public access into urban design [15]. Adopting urban planning practices such as City Beautiful and Garden City conceptions promotes the habitants perception of spatial configuration. These movements placed a strong emphasis on urban beautification, green spaces, and the blending of natural and urban environments.

Urban riverfront revitalization gained a renewed interest within the late 20th century. Theories like Kevin Lynch's "imageability" and Christopher Alexander's "A Pattern Language" emphasized the importance of public spaces and visual connections to water [16]. In an effort to rebuild a connection between urban residents and their natural surroundings. Planning approaches like "New Urbanism" advocated for mixed-use development, pedestrian-friendly promenades, and ecological restoration. Projects aimed at enhancing the quality of the water, developing public areas, and incorporating recreational facilities [17].

Contemporary urban planning approaches emphasize sustainability, resilience, and inclusivity in river waterfronts development. Significant importance was dedicated to new concepts such as green infrastructure, mixed-use development, and adaptive reuse of industrial sites. Cities are now recognized for their successful use of river waterfronts as a linear urban open space, with innovative planning and design [17].

4. Modeling Approaches for Pedestrian Behavior in Linear Public Spaces

The complex phenomenon of pedestrian behavior is influenced by an extensive spectrum of variables, such as human preferences, social interactions, environmental conditions, and design elements. These behaviors can be explored to provide significant insights into creating visually appealing, operationally functioning, and pedestrian-friendly public areas [18]. For the purpose of modeling and examining pedestrian movements in public areas, mathematical models provide useful tools as indicated by researchers [19].

The goal of these models is to mimic how individuals might move around an environment. Through the analysis of these simulations, planners and designers are able to identify possible safety issues, learn how design elements influence pedestrian flow, and eventually develop more user-friendly environments.

4.1. Visibility Graph Analysis (VGA)

4.1.1. Definition of VGA

Visibility graph analysis divides the urban space into a grid and evaluates the visual connections between these grid points to provide a quantitative method of examining spatial perception. This method has significant potential in various platforms. VGF can promote the enhancement of designing the urban open spaces to map with the human spatial cognition by analyzing the hidden views and sightlines [20]. Moreover, VGA can be utilized to strengthen security protocols by detecting possible blind areas that would need better illumination or surveillance techniques [19].

VGA thematic analysis can also be a beneficial tool that supports the spatial design aspects by maximizing space arrangement, and assuring good visibility in multi directions, and ultimately producing a more practical and user-friendly spatial experience offered through the linear configuration of the designated open space.

4.1.2. Benefits of Deploying VGA Analysis

The VGA emphasizes the level of understanding for users' spatial perception; it helps in understanding how people perceive the space, which is crucial for designing public areas, while defining the physical configurations of public spaces and respective user activities integration, [21].

The secondary added value is to enhance the degree of security, overseeing users safety measures within the varied special configuration designated spots, whether they are identified as non-hidden or hidden spots that might need improved surveillance or lighting for safety [20].

The designer is always in need of tools that allow for integrative design thinking to enable the optimization of layouts whether by manipulating spatial arrangements to accommodate useful design optimization for the layout of spaces enabling better visibility, or by integrating elements that thereby improve the overall spatial experience [19].

4.2. Axial Line Analysis (ALA)

4.2.1. Definition of ALA

Axial Line Analysis provides a reliable tool for assessing spatial connectivity in open spaces. This technique follows the approach of building a network of the longest uninterrupted lines (axial lines) that can be constructed in an urban open space. Through the examination of the interconnectivity and integration of these axial lines, ALA offers a reliable and relative approach related to pedestrian flow and urban planning [22]; It enables planners to have a full perspective on the evaluation of accessibility and movement, as an essential behavioral analysis guiding decision making regarding the

layout of public transportation, street networks, and open spaces in neighborhood design generally. Moreover, walkable urban spaces that encourage effective and secure movement for everyone can be approached with the use of ALA, which can be used to predict pedestrian movement patterns [23].

4.2.2. Benefits of Deploying ALA Analysis

The use of Axial line analysis allows for a thorough understanding of accessibility and connectivity levels among the extended linear as a spatial arrangement of open spaces, which enables planners to understand the impact of adopted design methods revolving around the potentials of offered potential of actual sites under study.

Throughout the various scenarios implicated by spatial configurations, there exists always a defined representation for Pedestrian Movement, and the ALA points out the prediction of pedestrian movement patterns, on which the planners can always make appropriate decisions in the design enabling more walkable urban areas [23].

4.3. Isovist Analysis

4.3.1. Definition of Isovist Analysis

Isovist analysis is an effective method for comprehending and modifying the visual experience in urban open spaces. This method enables creating "isovists," which represent the total visible area of the urban open space as viewed from a particular observer location [20]. Urban planners are able to obtain clear perception of visibility behaviors by examining the shape, dimensions, forms, and interconnectivity of these isovists. Isovist analysis can be used to optimize camera placement and identify potential blind spots in security design, in addition to maximizing visibility and sightlines, and improving the user experience [24].

4.3.2. Benefits of Deploying Isovist

Isovist enables a detailed analysis providing insights into further opportunities that can be seen from a particular defined point on a certain path while considering aspects necessary for security and surveillance planning [23].

The Architectural Design requires an analytical method that assists architects and planners in the design process to define related indoor/outdoor configurations to fulfill a certain desired visual characteristic, such as maximizing views or creating private areas related to the pre-defined program as well as the existing opportunities resulting from the application of the analytical tool.

The study also refers to the potentiality of users Experiences while answering for further needs to invest on actual spatial opportunities by optimizing sightlines

and visibility in regards to aligning buildings and open spaces configuration [25].

5. Multi-Method Approach for Studying Pedestrian Behavior in the Nile Waterfront Project

While modeling offers valuable insights, a comprehensive understanding of pedestrian behavior in linear public spaces requires a multi-method approach that combines flow collection techniques [26]. As presented in Figure 1, this research utilizes a multi-method approach to explore pedestrian flow and interactions within the context of the Nile Waterfront project, with a special emphasis on the "Mamsha-Ahl Masr" promenade. In order to have an adequate understanding of user experiences and preferences, this technique combines quantitative and qualitative data collection approaches [27], [28] and [29].

5.1. Assessment Method for Pedestrian Dynamics

The current research applies a multi-method approach to analyze and study the pedestrian movement and interactions within the context of the Nile Waterfront project, specifically focusing on the "Mamsha-Ahl Masr" promenade. It utilized three modeling approaches (VGA – ALA – and Isovist analysis, using Depth Map digital tool),[20] to understand the pedestrian behavior as well as the complexity of projected impact related to pedestrian dynamics [30]. The research adopts multiple tools for data gathering such as: direct observations, interviews, counting, mapping, and tracing[10]. The observations were conducted during day hours (from 4 am - 9 pm), for ten minutes per hour during weekends, in order to align the outcomes in terms of maximum occupancy of the promenade. Furthermore, the researchers are looking for a mean to compare the differences in activities resulting from changes in use related to the presence or absence of activities on typical days or seasonal touristic vacations, where the observations were supported by both integrative assessment methods to visualize on maps or with the use of digital tools, which aligns with the impact of visibility graphs on design decisions [31].

5.1.1. Counting

The density of the Visitors in specified location or along a certain traffic of user experience provides for an indicator that reflects the integral capacity of special capacities. Counting is a fundamental method for examining user behavior and the space's adaptability to changing uses over time [32].

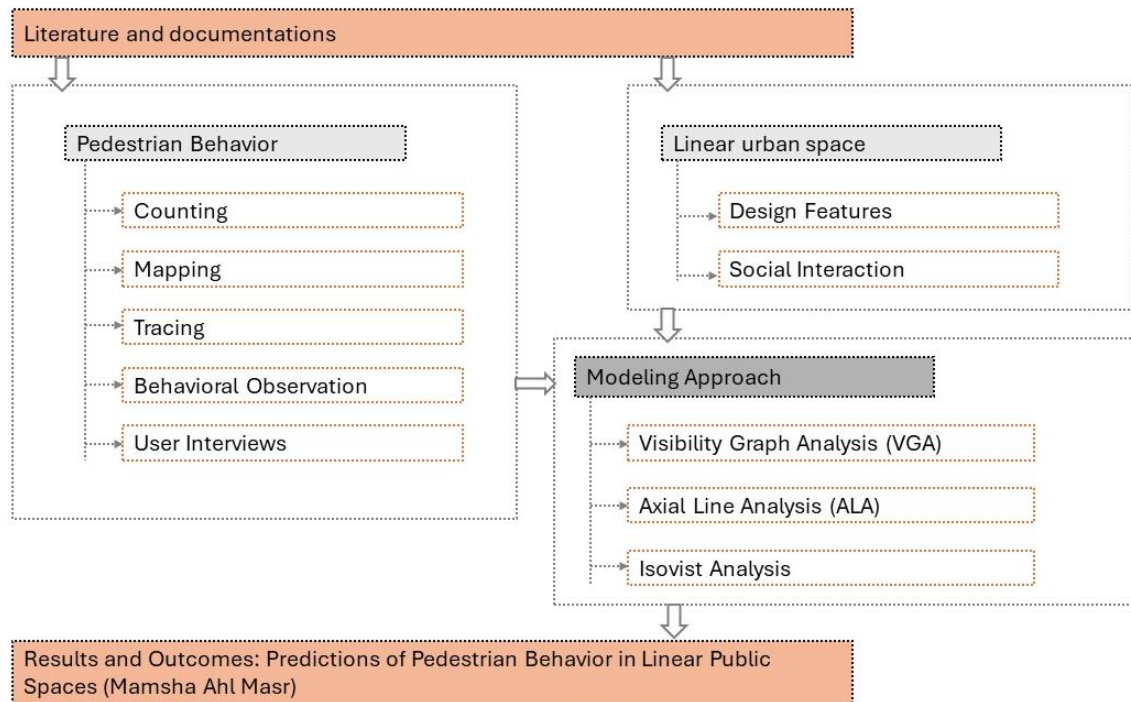


Figure 1. Research Integrative Assessment Methods (Source: Research Authors)

5.1.2. Mapping

Mapping tool records activities and events on an annotated map for the area being investigated. This technique is typically used to indicate users' stays, locating their gathering nodes (whether they are walking, standing, or staying). In addition to physical characteristics of the space, such as amenities, vegetation, and path types, help identify potential factors influencing pedestrian behavior, [18] [11].

5.1.3. Tracing

The tracing tool generates specific data regarding pedestrian movement patterns in addition to practical details about flow directions, circulation rates, speed, and route selection. Analysis of flow patterns, congestion spots, and pedestrian movement patterns are all provided by tracing [33].

5.2. Behavioral Observation

Observing the pedestrian behavior gives an opportunity for a deeper understanding of interactions, interrelations, social dynamics, and decision-making processes within an urban open space [32]. While further investigation can be verified with user Interviews: Interviews provide valuable opportunities to learn about experiences and opinions about comfort and safety [18]. Relative Observation feeds related to the case study analysis are represented Promenade Pedestrian Dynamics analysis in section 6; while the walkway was divided into three zones with variety of activity settings aligned on the linear paths of

the promenade.

6. "Mamsha Ahl Masr" as a Demonstration for a Linear Promenade Spatial Experience

The Ahl Masr Walk Project is a large-scale initiative undertaken by the Egyptian government to create a pedestrian walkway along the Nile River in Greater Cairo. Launched in September 2019; the project aims to improve the overall aesthetic of the Nile Corniche, promote environmental sustainability, and stimulate economic activity through tourism development. The project is divided into multiple phases, with the first two phases encompassing a total length of 5.2 kilometers. These phases incorporate green spaces, a promenade parallel to the river, buildings with shops, restaurants, and cafes, theaters, and designated parking areas. The second phase notably includes features like a floating restaurant and multiple concert venues. Future phases aim to extend the walkway to 8.2 kilometers, reaching from Shubra al-Khaimah in the north to Helwan in the south, [34]. The Ahl Masr Walk Project prioritizes environmental benefits by encouraging the use of bicycles through dedicated lanes and reducing car traffic congestion as described in the original project website [35]. Economically, the project seeks to capitalize on Egypt's position along the Nile River by establishing new attractions for water tourism. The project also creates commercial opportunities through the inclusion of shops and

restaurants within the walkway complex.

Other goals aligned with UN SDGs are considered of first priority including the challenges and mitigations processes adopted as part of the project execution plan like removing encroachments and pollution on the sides of the Nile.

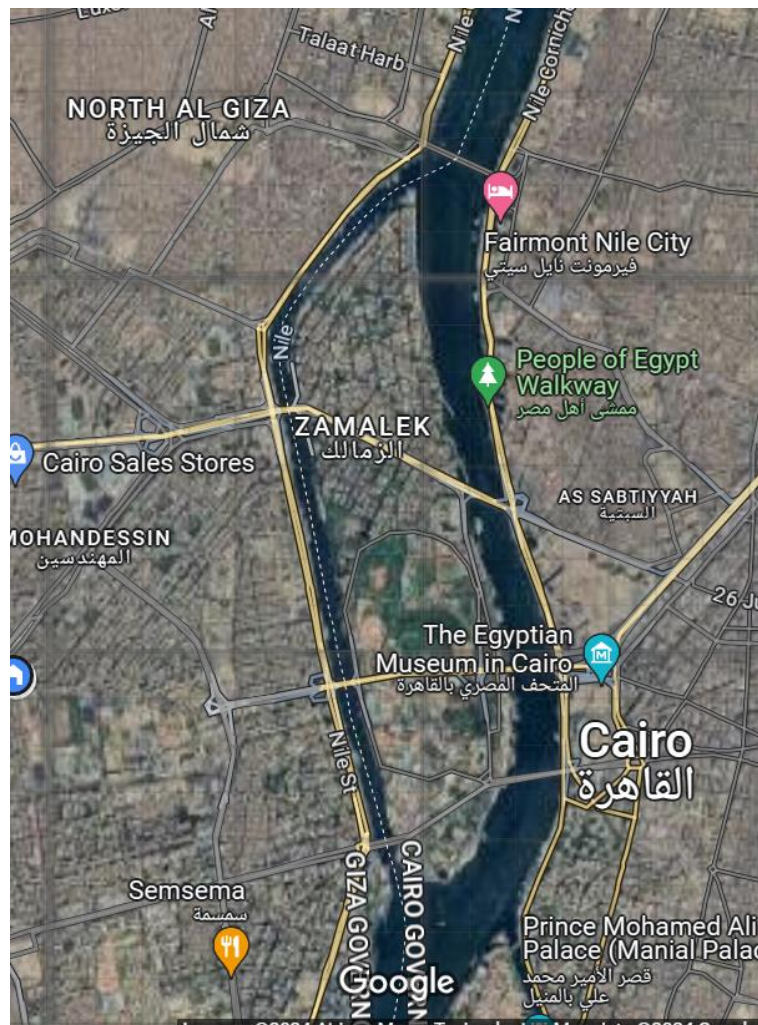
One of the Key Elements in the Walkway Project implementation is the sustainability features where the project design promotes environmental consciousness by incorporating dedicated bicycle lanes to reduce car traffic congestion. We can also consider the fact that providing public Access and amenities helps simulate the social cohesion and facilitate the visitors integration with offered facilities as it includes dedicated spaces to facilitate movement for people with disabilities; as well as additional amenities planned for the walkway, such as public restrooms, bike rentals, or informational kiosks, is not yet available [36].

The Project in his integral approach is anticipated to have an influential positive impact on social and economic scales beyond a direct influential increase in

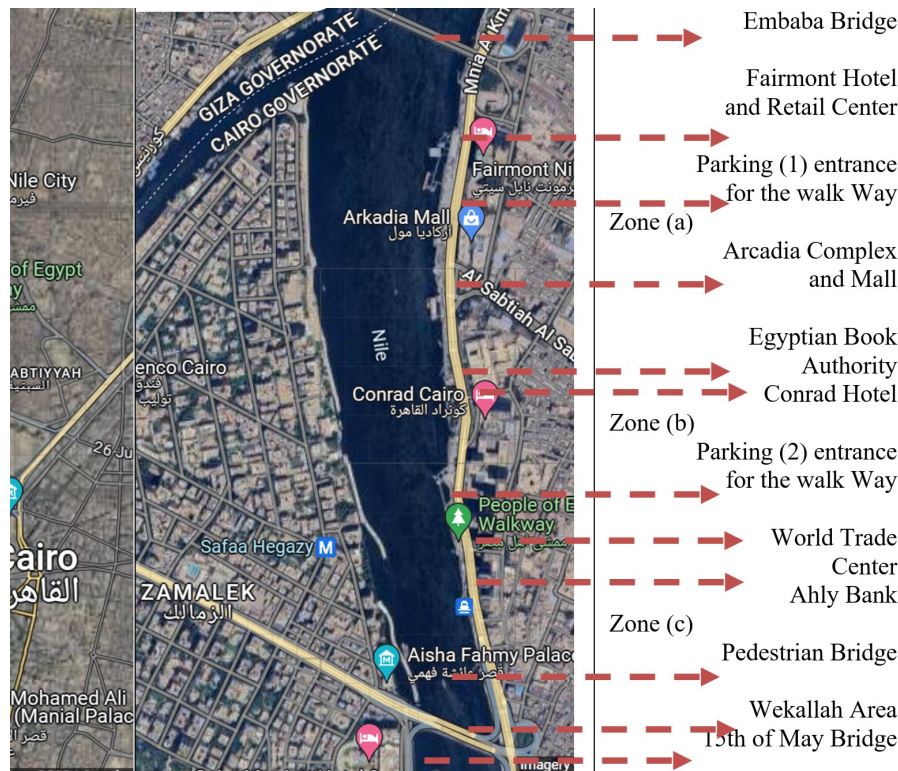
tourism activities and quality offered in Cairo. Potential benefits include job creation in the service and retail sectors surrounding the walkway, improved public health through increased physical activity encouraged by the pedestrian walkway, and potential for community development initiatives along the Nile Corniche.

6.1. Project Representation

The Area selected for the study is a one Kilometer Linear setting as an integral part of Phase 1, from Embaba Bridge to the 15th of May Bridge a dynamic zone well known for retail, office buildings, public facilities and local market areas, represented in Figure 2, where the major urban features are aligned with the main project criteria. The Study area is one Kilometer linear distance between “Embaba Bridge and “15th of May Bidge Infront of Zamalek area, inclusive of attraction points and landmarks such as public Facilities along the East bank of the Nile after Maspiro and Wekallah Area corresponding to walkway entrance gates and accessibility points.



(a) Project Localization One Kilometer between “Embaba Bridge and “15th of May Bidge Infront of Zamalek area



(b) Main Landmarks and Public Facilities along the East bank of the Nile after Maspuro and Wekallah Area corresponding to walkway entrance gates and accessibility points

Figure 2. Walkway Descriptive Map and localization of Study Area, (Research Authors)

6.2. Promenade Pedestrian Dynamics analysis

Modeling for Pedestrian Dynamics, in the study area more than 10 public gates, three service entrances and four parking access points are available, including two relevant connectivity paths towards 15th of May bridge, and the Ahly Bank pedestrian bridge, facilitating visitors movement and connectivity along the variety of activities aligned on the walkway.

These points include well-aligned stairs and ramps securing the capacity of public flow as well as disabilities comfort and guards checkpoints. Meanwhile observation for the actual user experience is guided by the researchers on a weekend afternoon (Saturday, May 11th, 2024), features are expected to inflate during summer time where there is seasonal increase in national and international tourism activities. According to the demonstration of selected pedestrian dynamics criteria in section 5.1. figure 3 represents the findings related to the linear setting of the study area.

6.2.1. Reflections on User Experience Behavioral Adaptations, an Observation Schematic Approach

For observation purposes, the study area is divided into three zones, with average similar lengths, along the 1 kilometer extended area of the walk way first executed

phase. Figure 4 (a,b,c) demonstrates the summary of major characteristics and the main attraction points according to visitor reflections and researchers observation during the pre-defined study for the three zones respectively.

The study outlines the methods used, such as user interviews and behavioral observation, but lacks specific details about the processes. For example, the user interview process involved selecting participants from diverse demographics to ensure inclusivity. Interviews were conducted in two phases: initial feedback on site usability and follow-up discussions after simulation-based. Behavioral observations were carried out during weekends and weekdays to capture varied activity patterns, ensuring reliability in the data.

Zone I from Embaba Bridge has allocation of branded hotels and restaurants as floating boats, gateways provide for more flow and show interest for international cliental, and a major attraction for touristic approach.

Pathways are of medium width in accordance to the visitors capacities but show more crowded vistas at the Nile taxi and fairies stations.

Further opportunities for resting are provided as grading near the secured gateways, it is also used in case of cultural exhibitions, and events, as well as temporal kiosk for retail settings, as shown in figure 4 (a).

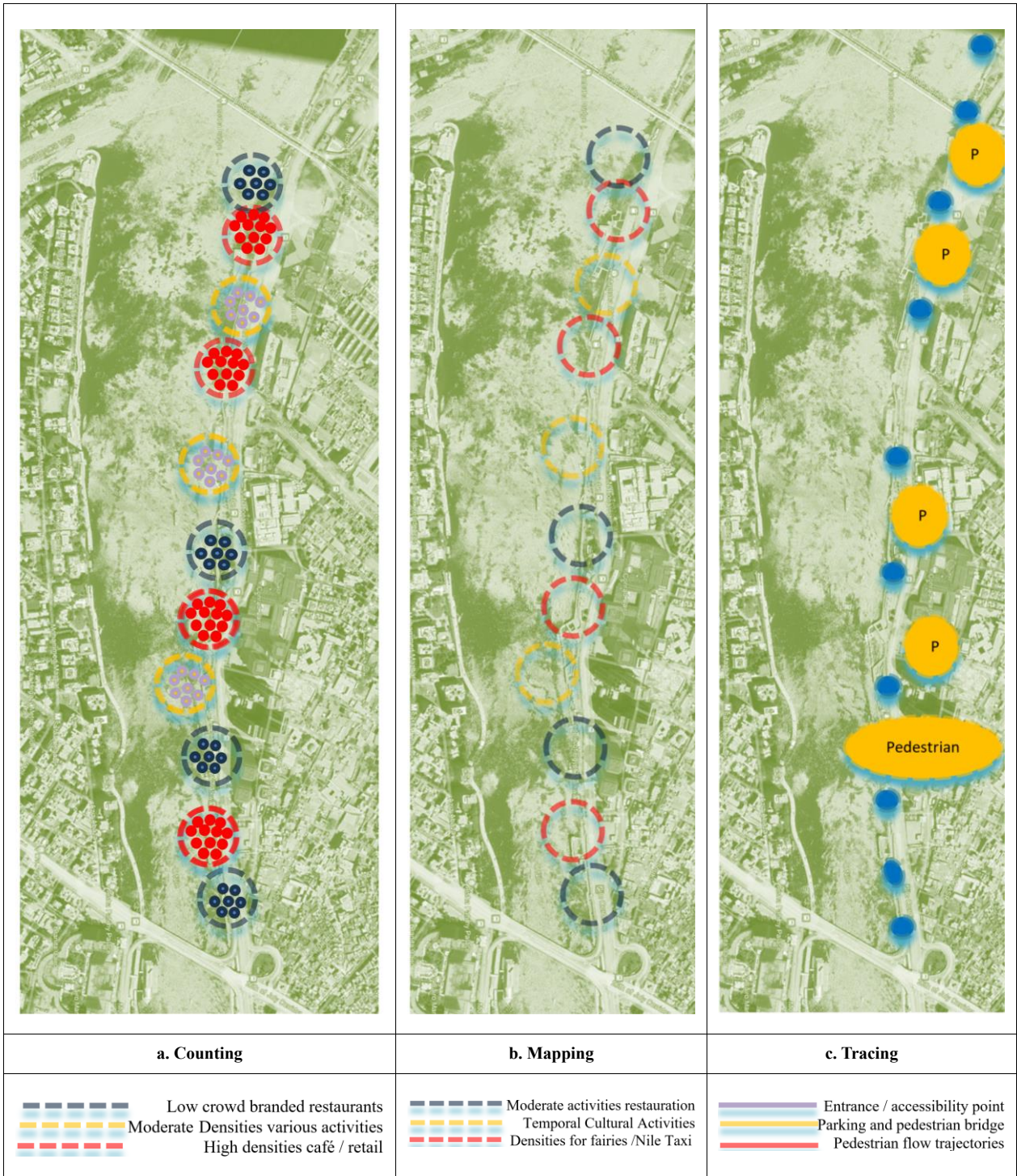


Figure 3. Pedestrian Dynamics Representation (source authors)

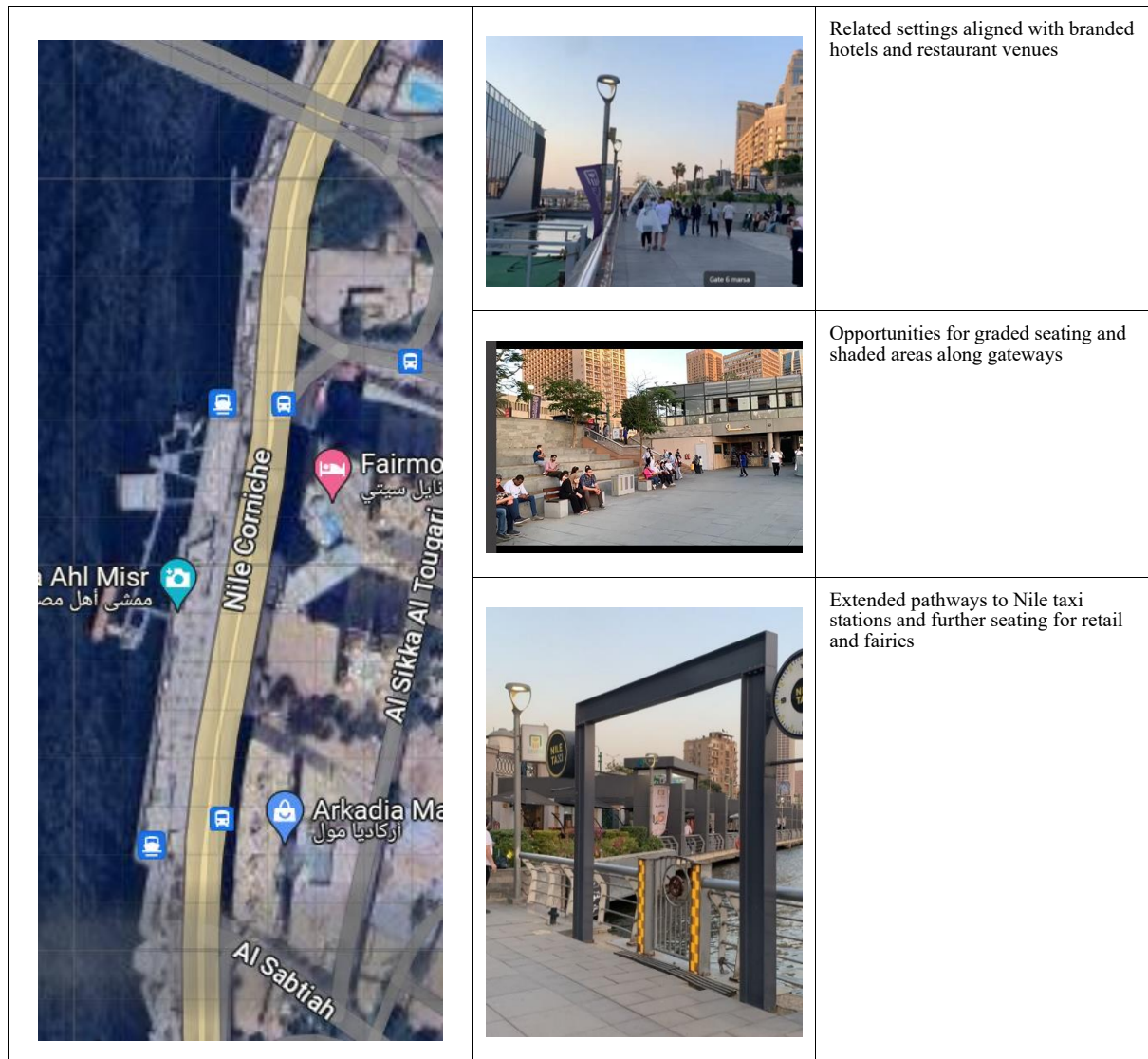


Figure 4 (a). Zone I Main Features, Observation outcome (source Researchers)

Challenges faceted in zone I can be summarized in the existence of the allocated stations for Nile Taxi as a gathering point, timely crowded and require more seating and waiting zones, which can be supported with other configurations of entertainment such as entertaining sense of musical background and celebration of the open view of the sunset toward the less crowded bank of Imbaba.

The overlooking landmarks at the beginning of Zone 1 as hotels and malls are perfectly connected with gateways towards the walkway of Mamsha Ahl Masr but a more integrated pedestrian solution such as tunnels or pedestrian bridges should be considered.

The following analysis represents the flow and connectivity between the various activities stimulating visitors choices, ensuring a fully integrative experience, considering the cultural approach distinguishing Zone II. Where a larger pathway and seating areas exist to enable maximum flow and connectivity with parking facilities and event areas.

Although the research is comprehensive, it has been expanded to explain methodological approaches in depth. For instance, user interviews were structured using a semi-open-ended format, allowing participants to discuss preferences and challenges freely. Responses were categorized into themes such as accessibility, safety, and comfort. The results were analyzed using qualitative coding methods to identify recurring patterns, further validating the study's findings. This independent analysis highlights the researchers' academic rigor in addressing pedestrian behavior comprehensively.

Zone II is directly set at the access gates Infront of El Sabtia district entrance, where more local shopping and retail services are provided on the city scale, yet this area has a more cultural activity settings due to the existence of bookstores and crafting retail outlets situated along the linear setting of the promenade Infront of the Egyptian National Organization for books and other mixed uses complexes.

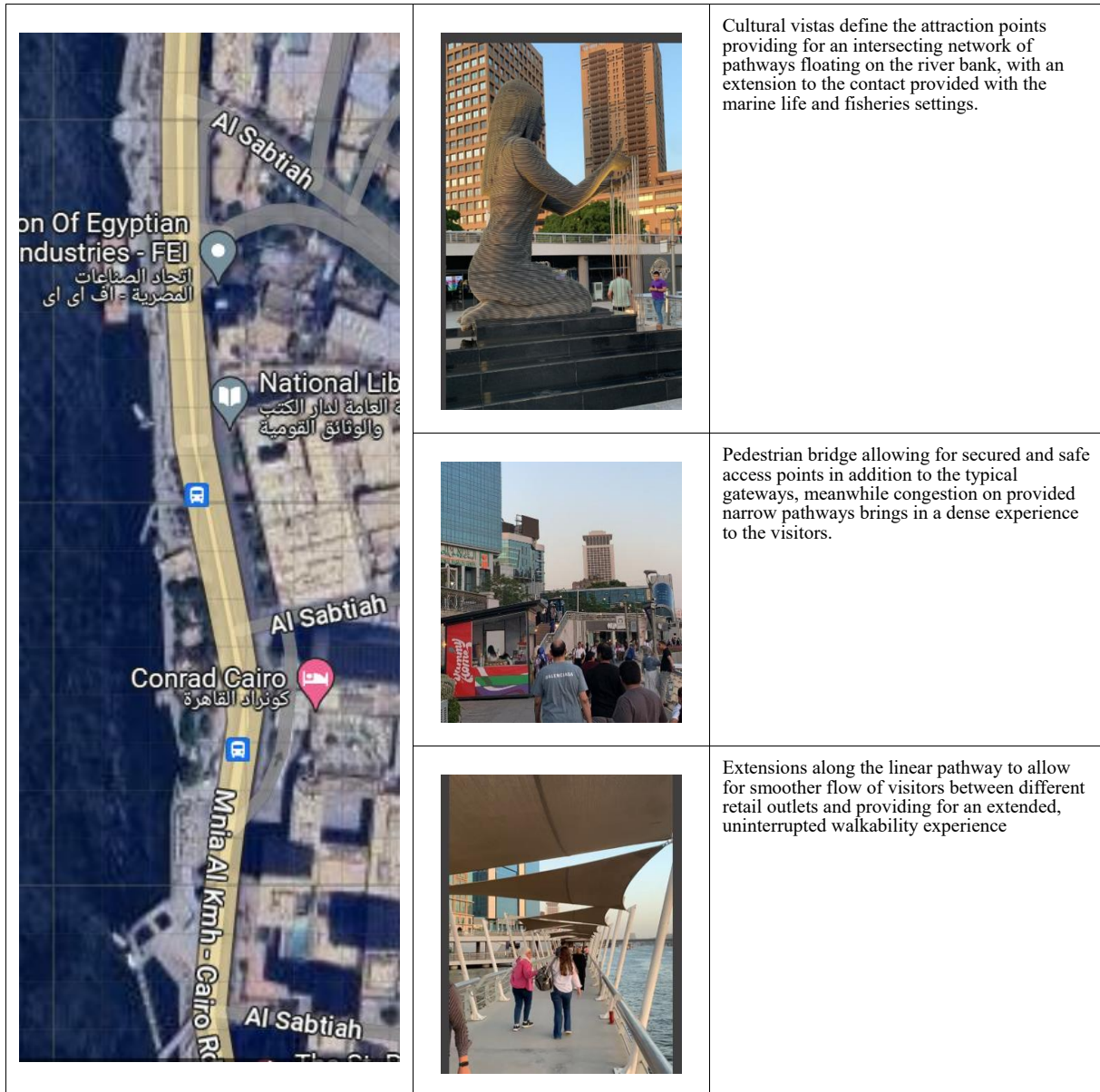


Figure 4 (b). Zone II Main Features, Observation outcome (source Researchers)

This zone is also situated between the below ground parking areas with direct access to the walkway, which increases the flow of visitors and requires more extended pathways on the riverbank as shown in figure 4 (b).

Zone III is the nearer to Maspiro area a walking distance from Cairo downtown along with other touristic destinations; hotels; office buildings, museums and local shopping facilities such as the Wekallah area.

Further facilities for retail and restorative outlets exist but with lower densities and more towards local brands.

A direct flow and vast vistas for pedestrians are provided due to the proximity of the Ahly Bank pedestrian bridge and the connected pedestrian access points towards the 15th of May bridge and Zamalek district, an explicit experience for pedestrian safety and promoting walkability for the user experience. Further facilities related to bike lanes and parking points; bus stops are observed towards the southern end of this zone. A detailed representation is shown in figure 4 (c).

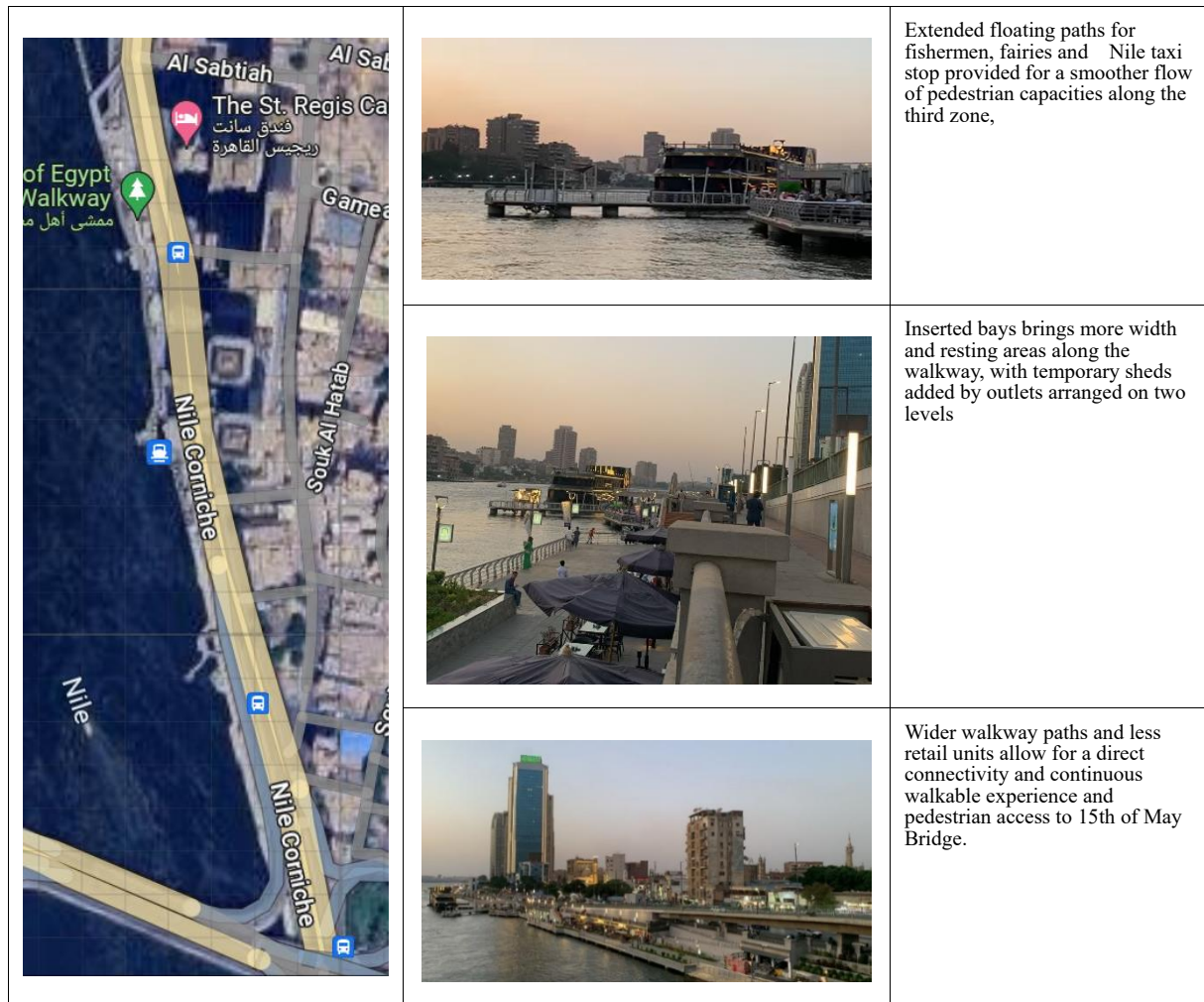


Figure 4 (C). Zone III Main Features, Observation outcome (source Researchers)

7. Simulation for Pedestrian Analytical Tools

Further demonstration is used to verify the observation outcome by using the Depth Map simulation tool, by running the pre-defined analytical methods represented in section 4 for the represented outcomes the simulation is running for the three zones under the same condition for the defined study localization, time, location and potential capacities.

The pedestrian flow simulation, colors represent different density levels: blue indicates low pedestrian activity, yellow signifies medium activity, and red marks high-density areas. These findings align with field observations, where crowding occurs around high-interest zones like performance stages or shaded seating areas. Such detailed explanation bridges the gap between simulation results and real-world validations.

7.1. Simulation for Visibility Graph Analysis (VGA)

The researchers used the main entrances and attraction

points as focal points for VGA, where in between distances form the required grid for analyzing visibility between these major points respectively in the three main zones of the study area. The analysis outcome is represented in Figure 5 (a), where the results help to understand user's spatial perception, and how they can perceive the offered facilities for accessibility points, Nile taxi stops, and cultural zones along the typical restorative destination.

7.2. Simulation for Axial Line Analysis (ALA)

The simulation is run by stipulating the longest sight line in the three zones respectively, where the connectivity and integration along the user trajectory is tested. The analysis outcome is represented in Figure 5 (b), where the results help the researchers define the potential of fine tuning of gate ways and main activities in the three sub-zones as well as an actual representation of pedestrian movement patterns which promotes walkability and minimize obstructions along the pathways.

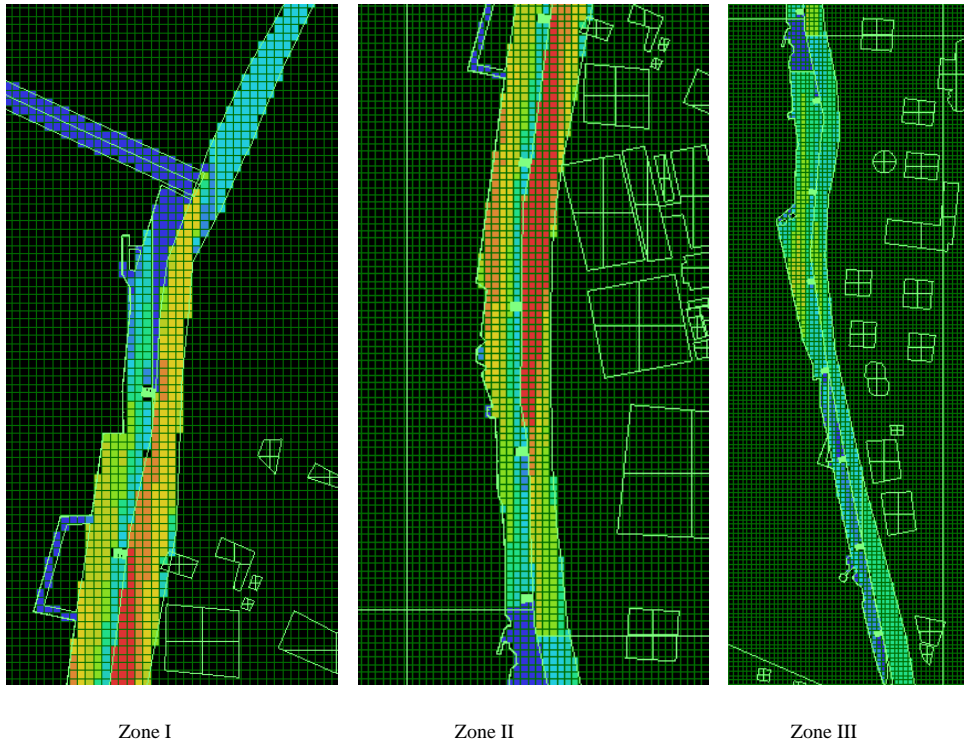


Figure 5 (a). Representation for the Simulation for Visibility Graph Analysis (VGA) (source Researchers)

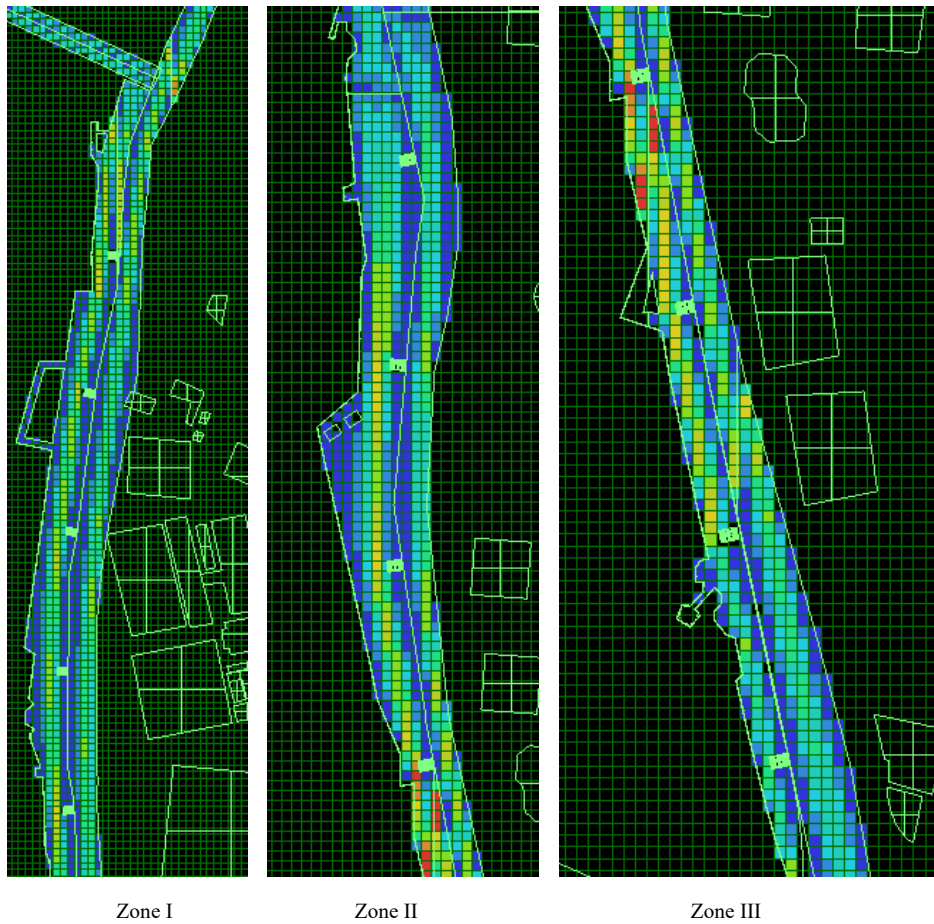


Figure 5 (b). Representation for the Simulation for Axial Linear Analysis (ALA) (source Researchers)

7.3. Simulation for Isovist Analysis

The simulation is generated to provide for potential viewsheds where visitors can have more interesting experience along the visible areas of the linear setting of the walkway, It is clear that the outcome uplifts the monotony of the extended pathways, and provides for more stipulated activity integration as well as detailed insights into what can be seen from a particular point, useful for security and surveillance planning; as per Figure 5 (c).

Isovist Analysis outcome plays an essential role for researchers and urban designers to define visual characteristics by maximizing views and creating new areas of retail along the walkway linear extension in the current or future extensions of Mamsha Ahl Masr Project.

7.4. Comparison of VGA, ALA, and Isovist Analysis Results on the Mamsha Ahl Masr Promenade

Areas with high visibility (VGA) and good connectivity

(ALA) are likely to be perceived as more attractive and accessible.

Conversely, areas with limited visibility (Isovist) and poor connectivity (ALA) might be perceived as less desirable. By combining these analyses, we can identify areas for improvement and optimize the promenade's design for a better pedestrian experience.

The analytical Representations enable the visualization of impactful decision-making related to the actual design allocation of activities, visitors flows and variety of scenarios implementation in an integrative approach.

The results are tested both in an experimental approach and with an actual representation of the promenade physical configuration in terms of capacities and generative design aspects.

The analysis also enables a timely configuration as well as investigating the impact of any additive urban impactful transformation with new activity setting or even visitors' needs.

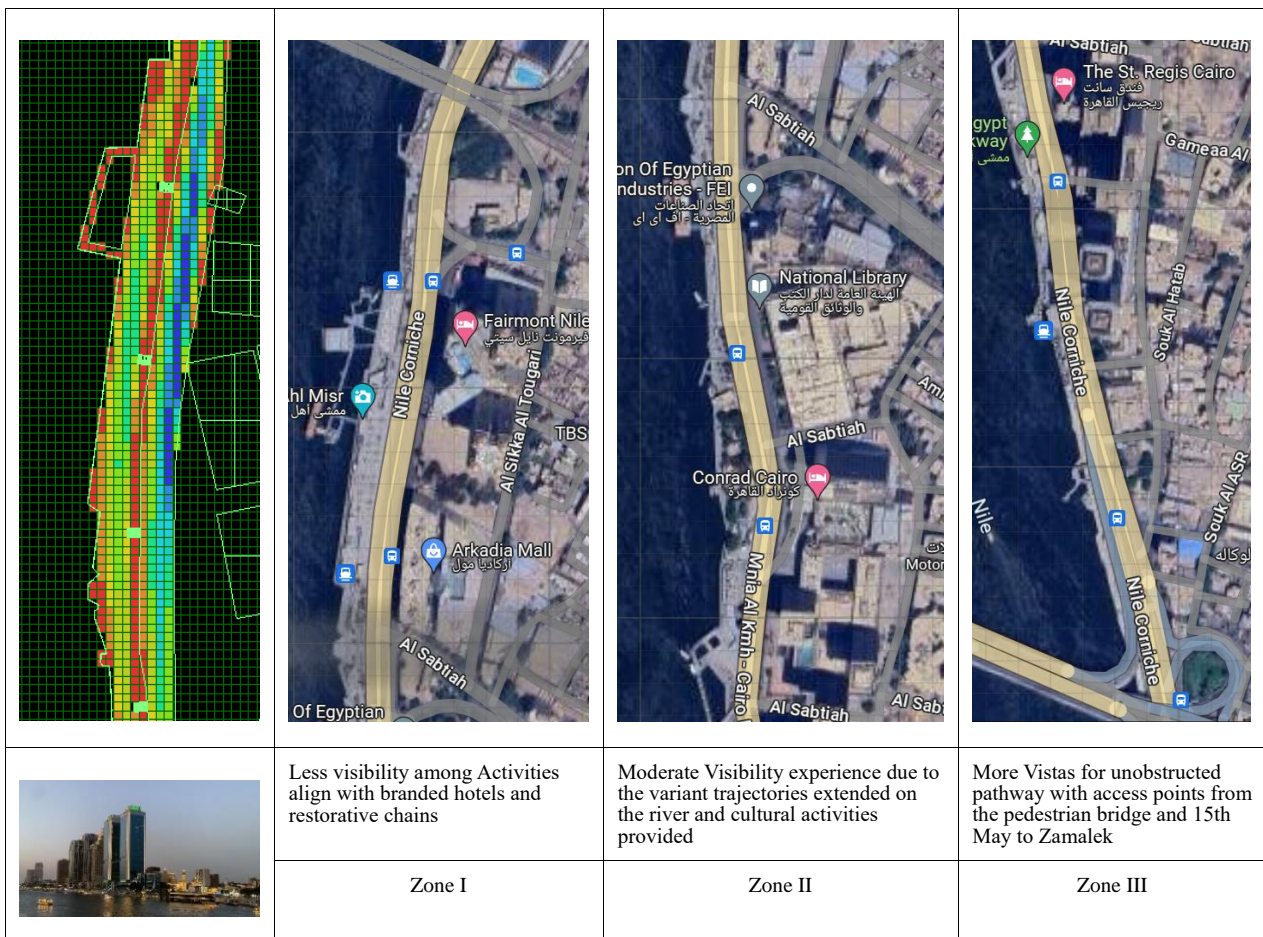


Figure 5 (c). Representation for the Simulation for Isovist Analysis (source Researchers)

Table 1. Comparison of VGA, ALA, and Isovist Analysis

Analysis Method	Focus	Insights
Visibility Graph Analysis (VGA)	Visual connections	Identified key vantage points and visual obstructions. Contributed to understanding pedestrian perception and navigation. Highlighted potential safety concerns through areas with limited visibility.
Axial Line Analysis (ALA)	Spatial connectivity	Examined the overall spatial structure and pedestrian movement. Identified major circulation paths and effectiveness of the layout in facilitating movement.
isovist Analysis	Visual experience	Determined the visible areas from specific points. Understood visual quality and pedestrian experience. Identified areas with limited views, impacting privacy and visual comfort.

8. Results and Findings

Pedestrian behavior was influenced by amenity concentration, with movement patterns favoring wider pathways and seating areas. Spatial analysis revealed the significance of visual connections, connectivity, and spatial quality for pedestrian experience. User perceptions emphasized safety, comfort, and social interaction. These findings underscore the intricate relationship between physical design, pedestrian behavior, and user satisfaction in shaping the overall quality of the linear public space.

Further integration of shaded seating areas with direct views of the river was found to enhance comfort and promote social interaction, while narrower pathways in high-traffic zones created congestion, limiting pedestrian movement. These observations underline the critical relationship between design features and user behavior.

The study also highlights the advantages and limitations of each methodological approach. For instance, while user interviews provided valuable qualitative insights into individual preferences and safety perceptions, multi-agent simulations offered quantitative data on pedestrian flow patterns. This dual-method approach allowed for cross-validation of findings, ensuring a more reliable analysis of spatial dynamics. By combining these methods, the researchers achieved a deeper understanding of how design elements influence pedestrian activity, reaffirming the importance of micro-scale design considerations in creating functional and enjoyable public spaces.

The research findings underscore the complex interplay between pedestrian behavior, spatial design, and user perception. The "Mamsha Ahl Masr" promenade offers valuable insights into the design and management of linear public spaces. By understanding these relationships, it is possible to create more pedestrian-friendly and engaging urban environments.

- **Pedestrian Behavior and Spatial Dynamic:** The study revealed distinct pedestrian behavior patterns along the "Mamsha Ahl Masr" promenade. Pedestrian density varied significantly across different zones, with higher concentrations observed near branded restaurants, cafes, and retail outlets.

Observations indicated a strong correlation between the presence of amenities and pedestrian activity

- **Impact of Design Features:** Analysis of design features demonstrated a clear influence on pedestrian movement. Wider pathways and the availability of seating areas were associated with increased pedestrian comfort and dwell time. Additionally, the presence of visual connections to the Nile and surrounding landmarks positively impacted pedestrian experience and satisfaction.
- **User Perceptions and Safety:** User interviews and observations indicated a strong preference for safe and accessible spaces. Pedestrians expressed concerns regarding potential congestion, especially during peak hours. The presence of security personnel and adequate lighting were identified as crucial factors for enhancing perceived safety.

To effectively apply the findings from the Mamsha Ahl Masr promenade to other linear public spaces, a systematic approach is essential. This involves a detailed comparison of the new site, followed by tailored data collection and analysis. By using VGA, ALA, and Isovist analysis, valuable insights into spatial quality and pedestrian behavior can be obtained. These insights inform the development of site-specific design recommendations, which should be continually refined based on user feedback. This approach ensures the creation of successful and engaging public spaces in diverse contexts

9. Further Research

To further enhance our understanding of linear public spaces, future research should delve into temporal variations in pedestrian behavior, the dynamics of social interactions, and the impact of environmental factors on pedestrian comfort. Advanced analytical techniques such as agent-based modeling, big data analytics, and machine learning can be employed to gain deeper insights. Cross-cultural comparisons and case studies will contribute to the identification of universal design principles. Finally, exploring the role of public policy and

integrating linear spaces into broader urban planning strategies are crucial for creating sustainable and equitable urban environments. The research utilizes the comparative approach to demonstrate the alignment of digital tools of analysis along the recognized typical observation and survey means of study. Therefore the authors recommend the integration of both methodological analytical measures in order to bring to the seen generative design approach and solid integral design decisions on the urban scale. The extension of this work is based on stipulating alternatives along the next phases of Mamsha Ahl Masr Project in regards of perceived users experience, in site observation and simulation outcomes.

The present study explores the intricate relationship between the physical configuration of riverbanks and their utilization by the public, with a specific focus on pedestrian behavior. The Nile Waterfront, particularly the "Mamsha Ahl Masr" promenade, served as a case study to investigate this complex interplay. A multifaceted methodological approach, encompassing automated trajectory analysis, environmental mapping, behavioral observation, and in-depth user interviews, was employed to comprehensively understand the factors influencing pedestrian movement patterns, the impact of design elements, and the emergence of safety concerns. Meanwhile the research findings according to the methodological approach adopted can form a base for future studies, experimenting on the quality of designed spaces and integrated activities during design phase as well as post construction visitors' responsiveness.

10. Conclusions

The present study delved into the intricate relationship between the physical configuration of riverbanks and their utilization by the public, with a specific focus on pedestrian behavior. The Nile Waterfront, particularly the "Mamsha Ahl Masr" promenade, served as a case study to investigate this complex interplay. A multifaceted methodological approach, encompassing automated trajectory analysis, environmental mapping, behavioral observation, and in-depth user interviews, was employed to comprehensively understand the factors influencing pedestrian movement patterns, the impact of design elements, and the emergence of safety concerns.

The research findings underscore the critical role of pedestrian behavior in shaping the success of linear public spaces. By integrating quantitative and qualitative data, the study revealed a nuanced understanding of how individuals interact with their environment within this specific context. The results emphasize the need to transcend traditional design paradigms, incorporating socio-economic factors and user-centric perspectives to create truly effective and inclusive spaces.

The study highlights the significance of pedestrian

activities and social interactions in shaping the overall character of urban environments. Moreover, the research underscores the importance of a micro-scale analysis to fully comprehend the intricate relationship between the physical environment and pedestrian behavior. The "Mamsha Ahl Masr" project serves as a compelling case study demonstrating the potential of riverfront revitalization to enhance quality of life and promote sustainable urban development. The integration of simulation tools, such as VGA, ALA, and Isovist analysis, proved invaluable in assessing the spatial performance of the promenade and informing design decisions. The research findings offer a robust foundation for optimizing pedestrian experiences in similar linear urban settings, emphasizing the critical role of walkability, safety, and social interaction.

Future research endeavors should investigate relatively the temporal dynamics of pedestrian behavior, exploring seasonal variations and the impact of specific events on usage patterns. Additionally, the integration of agent-based modeling can provide further insights into complex pedestrian interactions and the emergence of collective behaviors. By building upon the findings of this study, it is anticipated that the design of future linear public spaces can be significantly enhanced, leading to more vibrant, equitable, and sustainable urban environments.

Acknowledgments

The UFE, Université Française d'Egypte; <https://ufe.edu.eg> and Al Yamamah University KSA; Home - Al Yamamah University (yu.edu.sa) are recognized for their support of research and publication processes.

Author Contributions

This manuscript is produced in collaboration between the Authors in result of a thorough study for the onsite existing conditions and selection of assessment methods while concluding for future research and investigations by the three co-Authors, Aida Nayer, Samar Awad abdelhamed and Dalia Abdelfattah. Each author's contributions is an integral part of the final research presented in terms of: conceptualization, methodology, subject administration, validation, analysis, investigation, data collection, draft preparation, manuscript editing, and visualization. All authors have read and agreed with the manuscript before its submission and publication.

Funding

"Not applicable."

Institutional Review Board Statement

“Not applicable.” Individuals and companies who provided help during the research could be addressed here.

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