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RESEARCH ARTICLE

Utilizing Space Syntax Techniques to Understand the Relationship Between Spatial Configuration and Walkability in Urban Neighborhoods (Case Study: Valiasr Neighborhood, Tehran)

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ABSTRACT

The numerous benefits of walking, as one of the healthiest, simplest, and most cost-effective modes of transportation, have prompted many urban researchers to identify influential factors in pedestrian-oriented urbanism. These efforts aim to transform urban areas, including neighborhoods, into conducive environments for walking, thereby realizing related benefits such as sustainable development. Extensive research has confirmed the role of the built environment in attracting and distributing pedestrian movement, with a significant portion highlighting the relationship between urban configuration and walkability. This study aims to determine the role of urban configuration components in enhancing walkability at the neighborhood scale, selecting the Valiasr neighborhood in Tehran due to its location in the city's commercial center with a high volume of pedestrian traffic. For this purpose, after identifying spatial configuration components related to walkability – including accessibility, connectivity, and spatial arrangement components – key streets in the neighborhood's spatial configuration were identified using an initial analysis of spatial arrangement variables, followed by a survey of pedestrian volumes on selected streets. The evaluation of configuration components led to design recommendations in two layout patterns – grid and parallel block. The relationship between urban configuration and walkability, utilizing space syntax techniques, was identified after analyzing spatial arrangement variables in three different scenarios (existing condition and two proposed alternatives). The results indicate that accessibility components have the most significant impact on walkability in the Valiasr neighborhood. Following this, connectivity components were identified as influential in promoting pedestrian-oriented urbanism. Regarding spatial arrangement components, a comparison with prior research confirms that spatial elements do not operate independently of mixed-use and access to services and facilities. Instead, they play a role not in the formation of movement but in facilitating and directing it.

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1. Introduction

In response to the vibrant evolution of urban spaces and the growing recognition of walking as a fundamentally healthy, simple, and eco-friendly mode of transportation, our research seeks to delve into the intricate relationship between spatial configuration and walkability within urban neighborhoods. Specifically, this study targets the Valiasr neighborhood in Tehran, a bustling commercial hub known for its dense pedestrian traffic. Despite the acknowledged influence of the built environment on pedestrian dynamics, there exists a research gap in comprehensively understanding how various components of urban configuration, such as accessibility, connectivity, and spatial arrangement, collectively enhance or impede walkability at the neighborhood scale.

This research aims to bridge this gap by systematically examining the Valiasr neighborhood through the lens of space syntax techniques, offering insights into the role of urban configuration in fostering pedestrian-friendly environments. The significance of this inquiry extends beyond academic curiosity; it is poised to offer practical design interventions for urban planning and design professionals seeking to promote sustainable urban mobility and livable cities. Through meticulous analysis and modeling of spatial configuration patterns, this study aspires to provide actionable knowledge that can guide the transformation of urban neighborhoods into more walkable and engaging spaces.

The main objectives of this research are to identify the specific urban configuration components that significantly influence walkability, to evaluate these components within the context of Tehran's Valiasr neighborhood, and to propose design recommendations that enhance pedestrian movement and engagement. By achieving these aims, the study endeavors to contribute valuable perspectives to the discourse on pedestrian-oriented urban development, addressing both theoretical gaps and practical challenges in urban design.

Anticipated to offer comprehensive insights, the research outcomes are expected to elucidate the nuanced relationship between spatial configuration and walkability, highlighting the critical role of urban design in facilitating pedestrian movement. Furthermore, this study's structure unfolds in a sequential manner, beginning with an exploration of the theoretical underpinnings of walkability and spatial configuration, followed by a detailed case study analysis of the Valiasr neighborhood, and concluding with a discussion of findings and implications for urban design practice. Through this rigorous investigation, the research aims to underscore the paramount importance of thoughtful urban planning in fostering vibrant, walkable communities, thereby contributing to the broader goals of sustainable urban development and enhanced quality of life.

2. Theoretical Framework

2.1. The concept of Spatial Configuration in Urban Design

The term "spatial configuration" encompasses the systematic arrangement of urban elements and the network of spaces that facilitate movement and interaction within an urban environment [1]. It is through this lens that we can examine the intrinsic relationship between the physical layout of cities and the social life that unfolds within them. Jacobs (1961) poignantly illustrates this dynamic, asserting that vibrant street life, fostered by thoughtful spatial arrangement, is fundamental to the health and vitality of urban neighborhoods [2].

Gehl (2010) extends this discourse by emphasizing the human-centric approach to urban design, advocating for urban spaces that prioritize pedestrian comfort and engagement [3]. This perspective is critical in understanding walkability, as it highlights the necessity of designing urban environments that are not only accessible but also inviting to pedestrians. Similarly, Whyte's (1980) investigations into the social life of small urban spaces reveal how spatial configurations, even on a micro-scale, significantly influence how people interact with and navigate through their urban surroundings [4].

The concept of space syntax introduced by Hillier and Hanson (1984) provides a theoretical framework for analyzing spatial configurations and their impact on societal patterns, including walkability. This methodology underscores the importance of connectivity and accessibility in urban layouts, attributes that are essential for fostering pedestrian-friendly environments [1].

Further, Marshall (2005) delves into the structure of urban geometry, shedding light on how the layout of streets and patterns within urban areas shape user behavior [5]. This understanding is pivotal when considering the design of neighborhoods that encourage walking as a primary mode of transport. In reinforcing the link between urban design and sustainability, Porta and Renne (2005) demonstrate how specific indicators of spatial configuration can serve as benchmarks for sustainable urban development, with a particular focus on promoting walkability [6].

Collectively, these scholarly contributions underscore the complexity and significance of spatial configuration in urban design. They highlight how the deliberate arrangement of urban elements and the thoughtful design of public spaces can culminate in the creation of neighborhoods that are not only conducive to walking but are vibrant, sustainable, and reflective of the community's social fabric.

2.2. Pedestrian Orientation and Pedestrian-Oriented Neighborhoods

Walkability is a measure of how conducive an urban environment is for walking, taking into account factors such as the presence and quality of pedestrian infrastructure, the mix and proximity of land uses, the density and connectivity of the street network, and the overall perception of safety and comfort for pedestrians [7,8]. Enhancing walkability in urban areas is important for health, environmental, social, and economic reasons [8,9].

The concept of pedestrian-oriented neighborhoods is closely tied to walkability, as it refers to human-made environments designed to prioritize and facilitate pedestrian movement and access to local amenities. Key characteristics of pedestrian-oriented neighborhoods include high population and residential density, appropriate land use mix, accessible network of readable, direct, and interconnected paths, residents' access to more services including shops, green spaces, transportation lines, etc., security and safety, and the visual appeal and pleasant landscapes of local spaces and pathways [10]. Understanding the relationship between spatial configuration (the arrangement and connectivity of urban spaces) and walkability is crucial for informing urban planning and design strategies that can create more pedestrian-friendly environments and foster active transportation modes [11].

2.3. Space as a Platform for Activity

The built environment, particularly the arrangement and connectivity of urban spaces established by the street network, is referred to as spatial configuration. Spatial configuration is not merely a static representation of physical elements but rather a set of relationships between spaces that evolve over time. These spatial relationships can facilitate or constrain various human activities, including pedestrian movement [12,13].

The theory of space syntax, developed by Bill Hillier and colleagues, posits that spatial configuration alone can play a fundamental role in shaping social patterns and human behavior within the built environment [1]. This theory suggests that certain spaces within an urban network are more accessible and strategically positioned, thereby influencing pedestrian movement patterns and the distribution of activities [12].

By studying the patterns of spatial configuration, researchers can gain insights into the underlying forces that shape human activity and social dynamics within urban spaces. Moreover, spatial configuration theory recognizes that the relationship between space and human activity is reciprocal: while spatial arrangements can influence activity patterns, the way people use and appropriate urban spaces can also shape the evolution of spatial configurations over time [13].

3. Components of Spatial Configuration Affecting Walkability

Based on different definitions of walkability, studies conducted in the fields of environmental health and transportation engineering were reviewed. Health-related studies consider walking a physical activity related to physical health, while transportation studies regard it as the simplest mode of transportation.

Health-related studies, affirming the relationship between urban form and certain types of physical activities and some aspects of health, and their role in shaping walking and cycling and creating active, healthy, and livable communities, employ components such as density, land use mix, street network structure, and block configuration as effective components in pedestrian orientation. These studies, in addition to confirming the role of the density variable including residential and commercial units [14,15] and land use mix [15], identify access to destinations as the most important factor in shaping and distributing pedestrian movement [14], connectivity by providing continuous routes [14], street scale [15], the ratio of paths to nodes with a two-way and positive correlation with walking [16], and directness of pedestrian routes as criteria related to street network structure.

Some studies in this view conclude that increasing the number and density of intersections, and consequently smaller blocks, by providing more diverse routes, can enhance walkability. Variables related to local block structures such as length and size of blocks, density, and number of intersections can be evaluated as influential components in pedestrian orientation.

On the other hand, in the field of transportation engineering, the role of components such as density and land use mix, connectivity, access and proximity, and spatial features in pedestrian orientation and pedestrian movement has been studied. Berrigan, Pickle, and Dill (2010), using variables such as block length, block size, intersection density, percentage of four-way intersections, street density, the ratio of connected intersections, the ratio of node to link, network block features, path length, alpha index, and gamma index, assess connectivity as effective in pedestrian orientation by providing diverse routes [17].

The component of access and proximity to services and facilities can be measured with metric access and direct access variables. These variables distinguish well between different morphologies of street networks [17,18]. Recent transportation engineering studies, using the space syntax model, have assessed the role of spatial variables in pedestrian orientation and conclude that residents of neighborhoods with higher values of connectivity, access, and control walk more compared to residents of other neighborhoods [19–21].

The synthesis of studies from both perspectives shows that the components used in both views are very similar, so much so that the components of street network structure and block structure in environmental health studies overlap significantly with the connectivity components from the transportation engineering perspective. The components of access and spatial arrangement have also been studied in both views, with the difference that the transportation engineering view more precisely answers how these components play a role in pedestrian orientation [22– 25].

Given the above, the components to be studied in this research include the accessibility component and its indices (metric access, direct access; the ratio of metric access to direct access), the connectivity component and its indices (block length; block size; block density; intersection density; street density, the ratio of connected nodes, the ratio of node relationships, alpha index; gamma index) and the spatial arrangement component and its indices (integration, choice; control, depth). Table (1) shows the components and variables of spatial configuration affecting the walkability of urban neighborhoods, along with the method of calculation and analysis in this research.

Table 1. Components and variables of spatial configuration affecting walkability in urban neighborhoods, and methods of calculation and analysis.

Category	Variable	Definition and Calculation	Analysis Method
Access to Services and Facilities	Metric Access	Length of total street covered by all exit paths from that point, with a maximum specified threshold length. Calculation: Ratio of non-residential to residential use area within a walkable radius.	Higher values indicate easier and diverse access.
	Direct Access	Direct network distance, considering the minimum directional changes needed from a point. Calculation: Total length of paths within a walkable radius with less than 10-degree turns.	Higher values indicate straighter, easier paths for walking.
	Ratio of Two Accesses	Division of metric access values by direct access values.	Closer the value to one, the shorter the distance between destinations.
Connectivity	Block Length	Threshold for block lengths, ideal range between 90 to 180 meters.	Indicates appropriate block length for walkability.
	Block Size	Perimeter of blocks as measurable values.	Larger values indicate larger blocks.
	Intersection Density	Ratio of the number of intersections to the area of the region, with a standard of at least 50 blocks per square mile.	Higher values indicate higher connectivity.
	Street Density	Ratio of the total length of streets to the area of the region, with an ideal score of 15–20 miles per square mile.	Indicates street network density.
	Node-to-Link Ratio	Ratio of counted connections to total intersections and dead ends in the area.	Higher values indicate more connected street networks.
	Gamma Index	Ratio of number of connections in the network to the maximum possible connections between nodes.	Higher values indicate a more connected street network.
	Alpha Index	Ratio of actual circuits to the maximum possible number of circuits.	Higher values indicate a more connected street network.
Spatial Layout Features	Integration	Average number of intermediate lines needed to reach all city spaces from each line.	Higher values indicate more connections with spaces and a variety of paths, enhancing walkability.
	Control	Degree of choice each node has for nodes directly connected to it.	Directly related to route choice, higher values enhance walkability opportunities.
	Choice	Degree of choice for a specific route, indicating the extent of selecting that route to reach a destination.	Higher values indicate more space selection, enhancing walkability.
	Depth	Based on the number of steps required to travel from one point to other points.	Inversely related to walkability; higher values mean more intermediary spaces to traverse.

Source: [17, 26–30]

4. Research Methodology

This study adopts a quantitative methodological approach, primarily employing spatial mapping and analysis techniques to investigate the relationship between spatial configuration and walkability in urban neighborhoods. The choice of this methodological approach is justified by the study's aim to quantify and analyze the influence of spatial variables on pedestrian movement patterns, aligning with the theoretical foundations of space syntax.

Space syntax theory, developed by Bill Hillier and colleagues, posits that the spatial configuration of the built environment plays a crucial role in shaping human behavior and social dynamics [1]. This theory emphasizes the importance of understanding the relationships between individual urban spaces and their connections within the broader urban system, rather than focusing solely on the characteristics of individual spaces [12]. By quantifying and analyzing these spatial relationships, space syntax techniques enable the identification of pedestrian movement patterns and the exploration of the intricate interplay between spatial configuration and human activity.

The methodological approach of this study is grounded in the principles of space syntax theory, employing a combination of mapping techniques and urban morphological analysis to quantify and assess the spatial configuration components that influence walkability. The mapping component involves the use of GIS software and space syntax tools, such as Depthmap, to generate spatial representations of the urban environment and calculate various spatial configuration variables, including accessibility, connectivity, and spatial arrangement measures.

Urban morphological analysis is employed to complement the mapping techniques, providing a comprehensive understanding of the physical form and structure of the study area. This analysis involves the systematic examination of urban elements, such as street patterns, block sizes, and land use distributions, which contribute to the overall spatial configuration and pedestrian. By integrating urban morphological analysis with spatial mapping, the study aims to capture the multidimensional aspects of the built environment that shape walkability.

The variables observed in this study are directly derived from the literature review, which identified key spatial configuration components and their associated measures, such as metric access, direct access, block density, intersection density, integration, choice, and control [17, 31] Ewing & Cervero, 2010). These variables were selected based on their established relationships with pedestrian movement and walkability, as demonstrated in previous research.

To complement the quantitative analysis, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was conducted to provide a comprehensive understanding of the study area's context and to inform the development of design proposals. The SWOT analysis was based on direct observations and participant observations conducted by the researchers, allowing for an in-depth assessment of the physical and social characteristics of the neighborhood [32]. This qualitative component enriched the study's findings and facilitated the formulation of context-sensitive design recommendations.

The selection of the Valiasr neighborhood in Tehran as the case study area was based on its unique characteristics and significance as a commercial and administrative center within the city. The neighborhood's high pedestrian traffic volume and diverse land use patterns make it a suitable context for exploring the relationship between spatial configuration and walkability. Additionally, the findings from this case study have the potential to inform urban planning and design strategies in similar high-density urban contexts, contributing to the broader goal of promoting pedestrian-friendly environments.

By employing a mixed-methods approach that combines spatial mapping, urban morphological analysis, and qualitative observations, this study aims to provide a comprehensive understanding of the role of spatial configuration in enhancing walkability in urban neighborhoods.

5. Case Study

5.1. Location of the Area

The Valiasr neighborhood, situated in the south of District 6, has become part of the city center due to its geographic and functional centrality. It has unique features as District 6's national and international functional center, making it Tehran's commercial-administrative center. Nearly 5% of trips generated and more than 11% of trip destinations in Tehran's streets are allocated to this area.

5.2. Demographic and Social Aspect

Statistical data indicate that the majority of the neighborhood's population consists of young people aged 10 to 40 years. It seems that, demographically, the neighborhood has good potential for a greater inclination towards walking. Additionally, statistical analyses of the neighborhood's literacy rate show a high literacy rate. Examination of activity indicators reveals a high proportion of students in the neighborhood and a 29.5% employment rate among the active population (Figure 1).

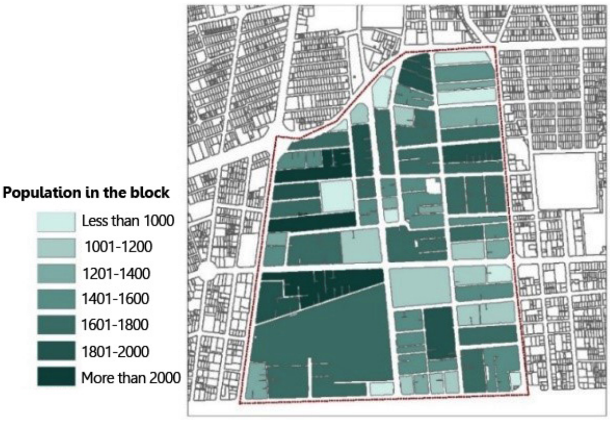


Figure 1. Population distribution in the blocks of Valiasr neighborhood of Tehran.

5.3. Morphological Aspect of Valiasr Neighborhood, Tehran

The Valiasr neighborhood in Tehran has a residential-service urban fabric. The functional radius of the neighborhood's land uses extends beyond the local area, having regional and supra-regional implications. This is exemplified by the presence of institutions like Amirkabir University of Technology and the University of Art, which provide city-wide services. This aspect attracts people from various parts of the city to the neighborhood. The neighborhood's easy access to public transportation systems, including two metro stations (City Theater and Valiasr Square) and proximity to Ferdowsi metro station, as well as access to the Bus Rapid Transit (BRT) system, facilitates the influx of people from other areas. All blocks in the neighborhood comprise mixed land uses, making the area predominantly residential-service oriented.

5.4. Communicational Structure and Access Network

Block Pattern

The Valiasr neighborhood in Tehran includes 4 superblocks and 74 blocks, mostly arranged in rectangular shapes within a grid network.

Mass and Space System

A low ratio of open spaces to build masses, reducing access opportunities and route diversity, can lead to decreased inclination towards walking.

Spatial Organization

The parts of the neighborhood functioning as active operational zones, attracting more population, include spatial elements like main arterial pathways along the neighborhood's periphery, primary circulation routes within the neighborhood, and commercial-service paths as linear elements (Figure 2).

The population-attracting land uses, public transportation stations, and functional intersections and nodes are also key point elements in the neighborhood's spatial organization.

This overview provides insights into the structural and spatial dynamics of the Valiasr neighborhood, highlighting how its morphological characteristics influence pedestrian activity and accessibility within the urban fabric.

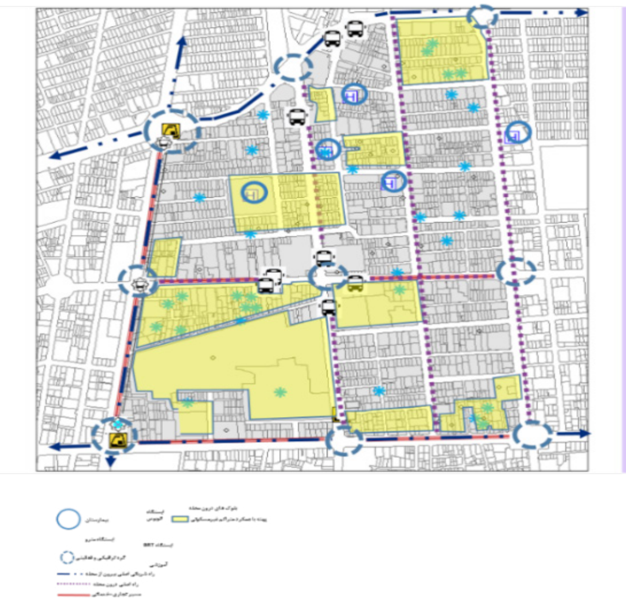


Figure 2. Spatial organization of Valiasr neighborhood in Tehran.

To better understand the area of study, a SWOT analysis was used. The following Table (Table 2) briefly highlights the most important points.

6. Research Findings

6.1 Current Conditions

Findings from the analysis of access to services and facilities indices are as following:

Metric Access

The shortness of blocks in the neighborhood has facilitated access to services, resulting in desirable metric access values. Most streets have access over 50%, with Karim Khan, Shahid Qarni, and Shadab streets having values less than 50%. The results indicate that on Nejatollahi Street, access to utilities is more feasible than on other main and selected streets in the area. The lowest metric access to non-residential uses was observed on Shadab and Vald streets (Table 3).

Table 2. SWOT analysis.

Threat	Opportunity	Weakness	Strength	Dimension
• The high number of students in the neighborhood and the possibility of the pedestrian network being inefficient	• Using the potential of the young population in terms of increasing walking opportunities • The possibility of raising the level of residents' awareness about the benefits of walking due to the high level of literacy in the neighborhood	• High unemployed population • High proportion of the population with work without income	• The neighborhood's young population • Literate and educated population • Distribution of appropriate sex ratio in the neighborhood	Demographic and social
• The possibility of residents not wanting to walk from the point of view of feeling safe and crowded • The possibility of reducing access opportunities and variety of routes due to the low ratio of open spaces to masses • The possibility of reducing the readability of the path due to the very small size of the blocks	• Improving the ability to walk around, considering the functional radius of regional and trans-regional neighborhood uses • Creating more varied and shorter routes considering the small and medium size of the neighborhood blocks from the point of view • Legibility and directness of the routes according to the checkered communication network • The possibility of increasing walking due to the small and medium size of the blocks in the small and medium neighborhood • Increasing pedestrian circulation due to the location in the residential-service zone	• Dead ends with irregular intersections in the structure of some blocks • The presence of more and more non-residents due to the functional radius of trans-regional and regional neighborhood uses and the inefficiency of the access network	• Mixing of uses in all blocks of the neighborhood • High number of movement destinations • Diversity of species and distribution of movement purposes	Morphological dimension
• Reducing the opportunity of pedestrian movement in different directions of the road due to the impossibility of pedestrian traffic in width only at intersections in some parts of the neighborhood. The possibility of reducing safety and security due to increasing the volume of traffic in the main arteries of the neighborhood	• Increasing mobility destinations accessible through the public transportation system of Ni Mahalleh • Increased readability due to the hierarchical structure of the neighborhood access network	• The interference of rider and pedestrian movement related to intersections of rider movement and pedestrian movement across the road • Regulating Valiasr neighborhood mainly based on horse movement and paying attention to pedestrian factors in the road network • Overflow of construction wastes and wastes into the sidewalk	• The richness of the communication structure of the neighborhood from the point of view of access to the public transportation system	structure and access network

Direct Access

Data on direct access in the study area show that Valiasr Street, due to fewer direction changes, has the highest direct access value in the neighborhood. Similarly, on Ayatollah Taleghani Street, the network structure and longer path lengths have reduced the number of direction changes, resulting in a high ratio of direct access. However, on Enghelab Street, the high density of streets and the dense grid network cause intersecting and angle-changing paths, affecting the direct access value in this area.

Ratio of Direct Access to Metric Access

On both Valiasr and Ayatollah Taleghani streets, the values related to the ratio of direct access to metric access are close to one, due to the few direction changes along the paths near these streets. On Enghelab Street, although both direct access and metric access values were the lowest, their proximity to each other made the ratio of these values in this street to be at a desirable threshold. Overall, due to the small size of blocks, appropriate street lengths, and an average number of direction changes in the area, the ratio of the two variables, direct access and metric access, is reported to be at a desirable level.

Pearson Correlation Results for Access Components

The correlation coefficient between the number of pedestrians and metric access is 0.534. This positive correlation indicates that as metric access increases, the number of pedestrians also increases. The highest correlation in the results obtained is between the number of pedestrians and the ratio of metric access to direct access, with a value of 0.885, the highest correlation among the components. This means that more than direct access and metric access, the directness of the path and fewer direction changes can impact walkability (Table 4).

Table 3. Analysis values of ratio of metric access and direct access in selected streets.

Street name	Metric to direct access ratio	Direct access	Metric access
Valiasr St	2.28	31.58	72
Henglab St. to the west	4.76	14.12	67.25
Qarni Street	1.33	33.12	44.20
Ayatollah Taleghani St	2.16	30.95	67
Hafez Street	2.23	26.03	58
Najatullahi St	2.24	31.25	70.04
Karimkhan Zand St	2.17	21.65	47
Shadab-Valdi Street	1.69	22.56	pp

Table 4. Correlation results between access variables and the number of pedestrians.

		Number of passers-by	Metric access	Direct access	Metric to direct access ratio
number of passers-by	Pearson Correlation	1	0.534**	0.643**	0.885
	Sig. (2-tailed)		0.000	0.000	0.000
	N	4	4	4	4
Metric access	Pearson Correlation	0.534**	1	0.798**	0.480**
	Sig. (2-tailed)	0.000		0.000	0.000
	N	4	4	4	4
Direct access	Pearson Correlation	0.643**	0.798**	1	0.775**
	Sig. (2-tailed)	0.000	0.000		0.000
	N	4	4	4	4
Metric to direct access ratio	Pearson Correlation	0.885	0.480**	0.775**	1**
	Sig. (2-tailed)	0.000	0.000	0.000	
	N	4	4	4	4

6.2 Findings from the Analysis of Connectivity Indices

The studied connectivity indices include block density, block size, intersection density, street density, ratio of connected nodes, ratio of node relationships, Alpha index, and Gamma index.

Block Length

The block length for pedestrians in the area is optimal, indicating shorter distances and more direct routes between locations. Most blocks in the neighborhood have an average block length. The two longest blocks in the area are associated with higher education institutions, namely the University of Art and Amirkabir University of Technology. These longer blocks suggest a different urban dynamic and potentially less frequent pedestrian crossings compared to other parts of the neighborhood (Table 5).

Table 5. Analysis of block length index in Valiasr neighborhood.

Block length (m)		
12	Minimum	Block length (m)
121	Medium	
875	Maximum	
24	The number of blocks above of the standard :180 meters	

Block Size

The size of blocks in the neighborhood is predominantly small, with only 4 large blocks and 2 very large blocks present. The reduced area and length of the blocks result in a greater number of pathways and their variety, thereby enhancing walkability in the neighborhood (Figure 3).

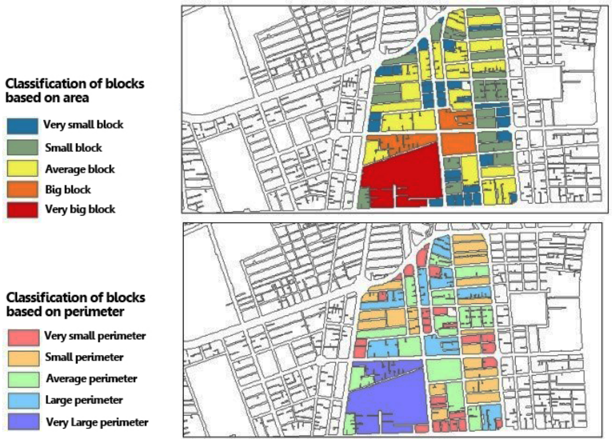


Figure 3. Classification of blocks in Valiasr neighborhood by perimeter and block area.

Block Density

The block density for the studied area was calculated as 61.05. According to existing standards, the Valiasr neighborhood accommodates a high density of blocks, confirmed by the small size and short length of the blocks in the area. This factor contributes to the neighborhood's high capacity to attract pedestrians due to block density.

Intersection Density

This was analyzed based on the ratio of the number of counted intersections to the total area of the neighborhood, considering whether intersections are three-way or four-way. A higher density of intersections indicates more available pathways for pedestrian movement, offering greater choice and route diversity. Thus, an increase in intersection density enhances walkability. In the Valiasr neighborhood of Tehran, despite the low number of four-way intersections, the high density of three-way intersections overall increases the number of intersections, thereby boosting walkability.

Street Density

The street density in the studied area is 20.17, which, according to the standard introduced by Bakhtiar (2013), identifies values between 3-5 miles per square mile (1.875 to 3.125 km per km^2) in rural areas and 15-20 miles per square mile (9.375 to 12.5 km per km^2) in urban areas as optimal for connectivity [16]. This indicates that the studied area has appropriate connectivity (Table 6).

Node-to-Link Ratio (Intersections)

In the studied area, the node-to-link ratio is 0.7, meaning that 70% of intersections do not lead to dead ends. This ratio is within the standard threshold for connected networks, indicating that the access network in the Valiasr neighborhood is well-connected.

Ratio of Connections to Nodes

The ratio in the area is 0.65, which is significantly lower than the standard. This indicates that the number of nodes (intersections) in the neighborhood is higher relative to the number of connections (streets). The high number of dead ends within the neighborhood could be a factor for this lower ratio. However, it's important to note that this variable does not provide a clear indication of walkability as it does not account for the length of connections, distances between nodes, or pedestrian distances, and thus cannot alone determine the pedestrian-friendliness of the neighborhood.

Gamma Index

The Gamma index value in the studied area is 0.18. Since this variable considers the total number of nodes and connections, the low value of this index is related to the lower number of connections compared to the number of nodes. Therefore, it can be inferred that the number of dead ends in the area has also played a role in estimating this variable, reducing the connectivity of the network.

Alpha Index

The Alpha index value in the area is 0.32. Similar to the Gamma index, the Alpha index is related to the number of connected nodes. The low value of this index indicates reduced walkability due to lower connectivity in the neighborhood (Table 7).

6.3. Findings from Spatial Configuration Analysis

The component of spatial configuration was assessed using four variables: Integration, Control, Choice, and Depth. These variables were evaluated against the collected data on pedestrian counts (Figure 4).

Table 6. Analysis of area index and density of intersections in Valiasr neighborhood.

Density of intersections	Block density	Street density	Number of intersections	Number of blocks	The length of the center line of the streets	Area
149	61.05	20.17	284	116	38.33	1.90

Table 7. Analysis of the indicators of the number of connected nodes, alpha and gamma in Valiasr neighborhood.

Number of dead ends	Number of intersections	Total number of nodes	Number of connections	Ratio of connections to nodes	Alpha index	Gamma index
119	284	402	260	0.65	0.22	.18

Integration

The average integration value in the area is 2.074, with the minimum at 0.499. The highest integration value is on Nejatollahi Street with 2.67 and a pedestrian count of 652. Valiasr Street, with the highest pedestrian count of 4728, has an integration value of 1.99. The analysis indicates no significant correlation between integration and the number of pedestrians.

Control

The average control parameter in the area is 1, with a minimum of 0.024 and a maximum of 3.54 on Nejatollahi Street, which has a pedestrian count of 652. Valiasr Street, with the highest pedestrian count of 4728 in the area, has a control value of 3.34.

Choice

The average choice parameter in the area is 0.024, with a minimum of 0 and a maximum of 0.663. The highest choice value is on Nejatollahi Street with a pedestrian count of 652. Valiasr Street, with the highest pedestrian count of 4728, has a choice value of 6.

Depth

The average depth parameter in the area is 198.573, with a minimum of 8 and a maximum of 515. The highest depth value is on Hafez Street with a pedestrian count of 692. Valiasr Street, with the highest pedestrian count of 4728, has a depth value of 2.13.

7. Presentation and Assessment of Proposed Designs

Following the evaluation of components in the studied area, proposed solutions to enhance walkability were utilized to develop design patterns, which are briefly described in (Table 8).

Considering the structure of the Valiasr neighborhood, which combines a grid network, parallel divisions, and dead ends, two different patterns were proposed based on the grid network and parallel divisions. These proposals were informed by the five categories (grid network, parallel segments, curved alignments, nodes, and spirals, and a combination of linear and spiral structures) of the access network structure introduced by Southworth and Owens (1993).

7.1. Proposed Design Based on the Grid Network Pattern

The grid network pattern is a simple system of two sets of parallel streets intersecting at right angles to form a pattern of equal square or rectangular blocks (Southworth and Owens, 1993). For designing this alternative in the Valiasr neighborhood, efforts were made to reduce the number of dead ends and increase the number of four-way intersections. Additionally, the design focused on maintaining straight paths and minimizing direction changes. In certain areas, based on the land uses, dead ends and block structures were preserved to maintain the neighborhood's character (Figure 5).

7.2. Proposed Design Based on the Parallel Division Pattern

In this pattern, blocks are arranged as narrow rectangles or L-shaped configurations. Despite having nearly the same street size as the grid network, this pattern significantly reduces the number of blocks and access points (Southworth and Owens, 1993). The design of this alternative aimed to extend streets in parallel directions, terminating at specific intersections with closed-end blocks. Similar to the grid pattern, the sections associated with significant land uses remained unchanged (Figure 6).

Table 8. Design proposals with evaluation of components in current conditions.

Component	Design proposal
Access to services and facilities	– Short block length – Not changing the angle by more than ten degrees
Connectivity	– Keeping the size of the blocks constant – Increasing the number of intersections – Increasing the number of streets – Increasing the number of connections Reducing the number of dead ends
Space Syntax Features	– Increasing the connection of a space to all local spaces – Increasing the number of interfaces – Increasing the chance of choosing a space in a node – Increasing the number of accesses

Figure 5. The structure of the proposed grid layout.

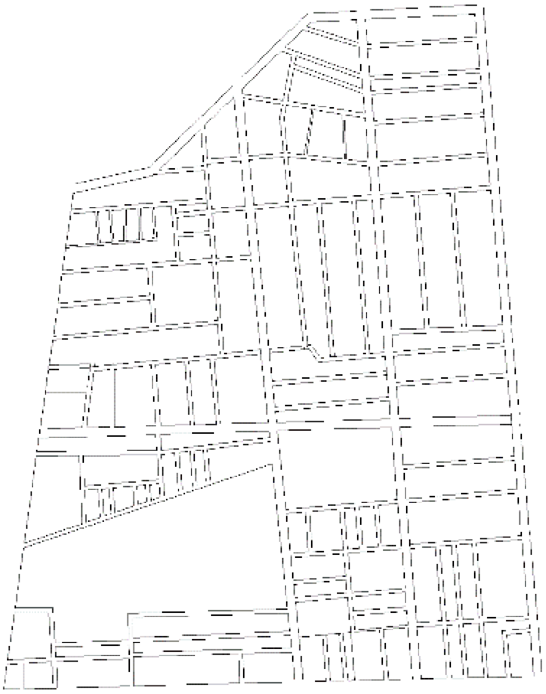


Figure 6. The structure of the proposed layout of parallel plots.

7.3. Evaluation of Spatial Configuration Components in Proposed Patterns

Integration Parameter

The analysis of the integration parameter reveals the following:

These results indicate that the average integration in Alternative 1 (Figure 7b).is slightly lower than the existing condition, suggesting a reduction in the overall connectedness and integration of the street network. On the other hand, Alternative 2 (Figure 7c).shows an increase in the average integration compared to the current condition, suggesting an improvement in terms of connectivity and pedestrian accessibility (Figure 7).

Control Parameter

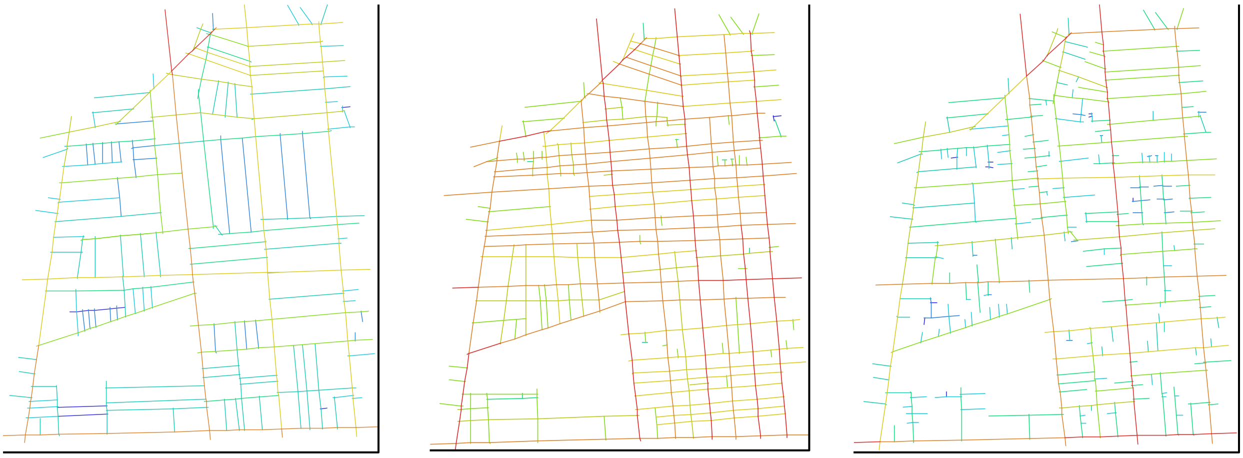
The analysis of the acquired data indicates that the maximum control parameter in the current condition is 22.256 (Figure 8a). This value decreases to 15.38 in Alternative 1 (Figure 8b) and further to 13.03 in Alternative 2. Thus, in descending order, the existing condition, Alternative 1, and Alternative 2 (Figure 8c) exhibit the highest control parameters. The concept of 'control' can be interpreted as the degree of selection in a network, representing the probability of choosing a space at an urban node. Considering that this parameter significantly influences the increase or decrease in pedestrian flow, the data suggest that both proposed alternatives are less effective in this regard. The reduction in the control parameter in the alternatives points to a decrease in route selection possibilities at intersections, which may impact the urban area's overall walkability and pedestrian experience (Figure 8).

Selection Parameter

The average selection parameter for Alternative 1 is 587.005, with the minimum selection parameter in the range being equal to 0, and the maximum selection parameter in the range being equal to 11,630 (Figure 9b). The average selection parameter for Alternative 2 is 349.664, with the minimum selection parameter in the range being 0 and the maximum selection parameter in the range being 5,258 (Figure 9c). The highest selection parameter in the range is less than 525 (Figure 9).

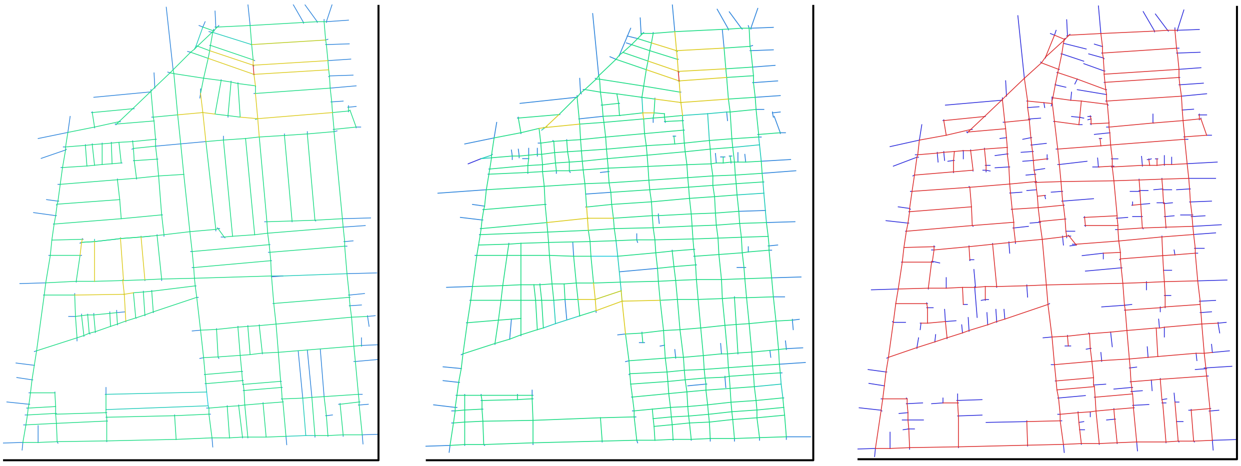
Depth Parameter

Based on the data analysis, it is indicated that the average depth parameter for Alternative 1 is 229.30, with the minimum depth parameter within the range being 12, and the maximum depth parameter reaching 478 (Figure 10b). The greatest frequency of the depth parameter in the range falls between 245 and 291.60. The average depth parameter for Alternative2 stands at 187.48, with the minimum depth parameter in the range being 15, and the maximum depth parameter within the range being 323 (Figure 10c). The most frequent depth parameter values for this alternative range from 169 to 199.80 (Figure 10).



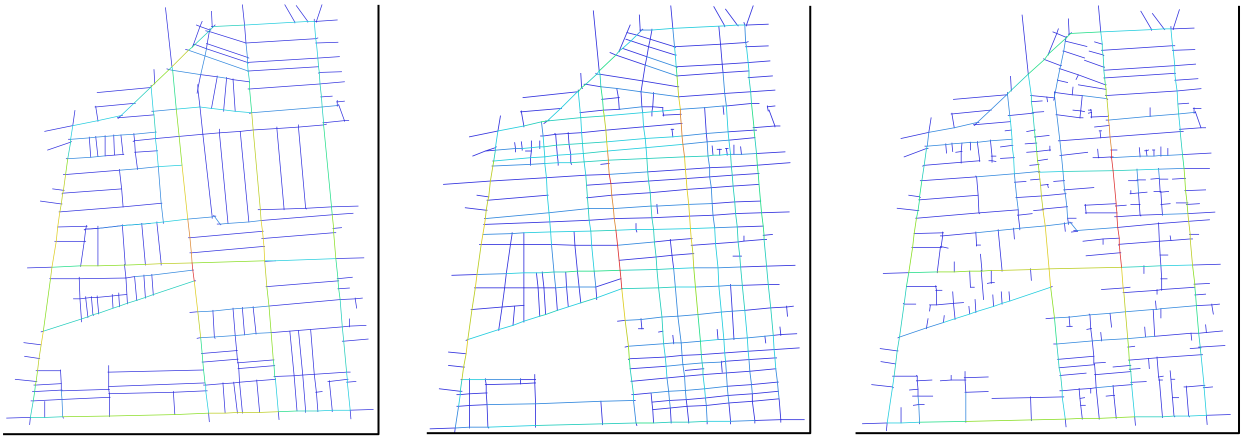
C B A

Figure 7. Evaluation of the integration parameter in different urban design patterns. (A) integration Parameter in the Existing Condition; (B) integration Parameter in the Proposed Grid Network Pattern; (C) integration Parameter in the Proposed Parallel Division Pattern.



C B A

Figure 8. (A) control Parameter in the Existing Condition; (B) control Parameter in the Proposed Grid Network Pattern; (C) control Parameter in the Proposed Parallel Division Pattern.



C B A

Figure 9. (A) selection Parameter in the Current State; (B) selection Parameter in the Proposed Chessboard Network Pattern; (C) selection Parameter in the Proposed Parallel Segments Pattern.

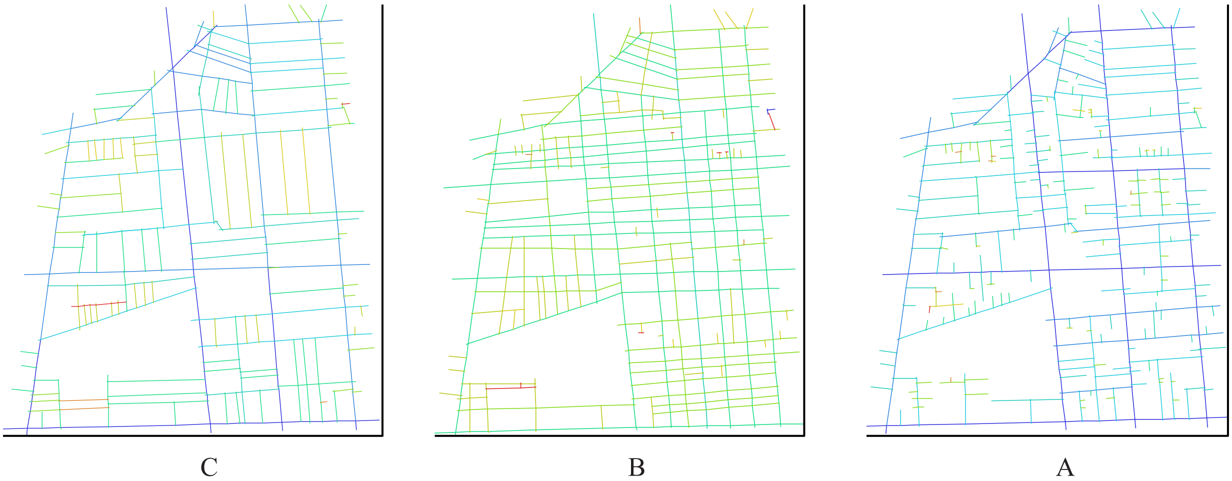


Figure 10. (A) depth Parameter in the Existing Condition; (B) depth Parameter in the Proposed Chessboard Network Pattern; (C) depth Parameter in the Proposed Parallel Segments Pattern.

8.Discussion and Conclusion

This section presents the findings of the study, organized according to the three main components of spatial configuration identified in the literature review: accessibility, connectivity, and spatial arrangement. The findings are discussed in relation to their impact on walkability in the Valiasr neighborhood of Tehran.

8.1 Findings of the Study

Accessibility

The analysis of access to services and facilities indices revealed that the ratio of metric access to direct access had the strongest correlation with the number of pedestrians (r = 0.885). This finding suggests that the directness of paths and fewer interruptions play a more prominent role in attracting pedestrians than proximity alone, measured by metric distance. The results indicate that smaller blocks within the area, by providing varied access to destinations, contribute to high metric accessibility, which in turn promotes walkability.

These findings align with previous research highlighting the importance of direct access and route directness in encouraging pedestrian movement [17, 31]. The high correlation between the ratio of metric to direct access and pedestrian volume underscores the significance of minimizing direction changes and path interruptions in urban design strategies aimed at enhancing walkability.

Connectivity

The evaluation of connectivity indices revealed that the chessboard network structure in the Valiasr neighborhood, characterized by smaller blocks, dense streets, and intersections, has facilitated a suitable volume of pedestrian traffic. However, the high number of dead-ends in the area resulted in lower values for the ratio of connections to nodes, the Gamma index, and the Alpha index, suggesting reduced connectivity.

The proposed design alternatives, which aimed to reduce the number of dead-ends, demonstrated the potential to improve connectivity and consequently enhance walkability. These findings align with previous studies that have identified the positive impact of increased connectivity, through factors such as block density, intersection density, and street density, on pedestrian movement [17].

Spatial Arrangement

The analysis of spatial configuration variables, including integration, control, choice, and depth, did not reveal a significant correlation with the number of pedestrians in the Valiasr neighborhood. This finding suggests that walkability in this area, due to its location in the city's commercial center and its unique functional position, is more influenced by the functional performance of the area and the distribution of land uses than by the physical structure related to the access network.

This observation aligns with previous research indicating that spatial layout variables indirectly affect walkability by influencing location choices and accessibility to land uses. The role of spatial configuration components in this context is not in generating pedestrian traffic but rather in facilitating and directing it.

The analysis of spatial configuration components in the proposed design alternatives revealed that, with the exception of the integration component, the parallel segments structure allocated higher values to variables such as choice, control, and depth. This can be attributed to the longer streets and fewer connections in this pattern, as longer paths and reduced access inversely relate to choice and control variables.

8.2 Recommendations

Based on the findings of the paper, the following recommendations can be made for enhancing walkability in urban neighborhoods through spatial configuration interventions:

- Prioritize the reduction of path interruptions and direction changes by promoting smaller block sizes and minimizing dead-ends. This can be achieved through the implementation of grid network or parallel division patterns, as demonstrated in the proposed design alternatives.

- Increase connectivity by providing dense street networks, high intersection density, and a greater ratio of connected nodes. This can be accomplished by reducing the number of dead-ends and promoting a well-connected access network.

- Consider the functional performance and land use distribution of the area in addition to the physical structure of the access network. While spatial configuration components play a role in facilitating and directing pedestrian movement, they do not operate independently of mixed-use and access to services and facilities.

- Employ a combination of quantitative spatial analysis techniques, such as space syntax, and qualitative assessments of the urban context to inform context-sensitive design solutions for enhancing walkability. of the urban context to inform context-sensitive design solutions for enhancing walkability.

- Explore the role of travel purpose and its influence on the relationship between spatial configuration components and walkability, as this factor may impact the effectiveness of design interventions aimed at promoting pedestrian-oriented urbanism.

By implementing these recommendations, urban designers can create more walkable and pedestrian-friendly urban environments, contributing to the broader goals of sustainable urban development, public health, and community well-being.

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