REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PÁG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

Recibido: 01-02-2025
Aceptado: 02-06-2025

USING FUZZY INFERENCE SYSTEMS TO EVALUATE SIDEWALK QUALITY IN AHVAZ, IRAN[1]

USO DE SISTEMAS DE INFERENCIA DIFUSA PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN

MAJID GOODARZI 2
ZAHRA SOLTANI 3
NOORA ABYAT 4

1 This article is based on the author's research work in the field of Geography and Urban Planning

2 PhD in Urban Planning
Associate Professor of Geography and Urban Planning, Department of Geography and Urban Planning
Shahid Chamran University of Ahvaz, Ahvaz, Iran
https://orcid.org/0000-0001-7982-8027
m.goodarzi@scu.ac.ir

3 PhD in Rural Planning
Associate Professor of Geography and Rural Planning, Department of Geography and Urban Planning
Shahid Chamran University of Ahvaz, Ahvaz, Iran
https://orcid.org/0000-0001-5876-0473
z.soltani@scu.ac.ir

4 Master's in Geography and Urban Planning
Ph.D student of Geography and Urban Planning, Department of Geography and Urban Planning
Shahid Chamran University of Ahvaz, Ahvaz, Iran
https://orcid.org/0009-0002-3028-8618
noraabyat@yahoo.com

https://doi.org/10.22320/07183607.2025.28.51.05

Las veredas y los peatones son componentes vitales de la vida urbana y desempeñan un papel crucial para mantener la sustentabilidad y habitabilidad de las ciudades. Las veredas de alta calidad contribuyen a crear espacios urbanos más seguros y vibrantes. Dados los importantes beneficios sociales, económicos y culturales de caminar, los esfuerzos para mejorar las condiciones de las veredas han atraído una atención considerable en los últimos años. Este estudio busca evaluar el estado y la calidad de las veredas urbanas en Ahvaz, una ciudad en el suroeste de Irán. La evaluación se basa en datos recopilados a través de cuestionarios completados por expertos en geografía y planificación urbana. Se empleó un sistema de inferencia difusa implementado en el software MATLAB para identificar las reglas subyacentes a la evaluación de la calidad de las veredas. Posteriormente, los datos del cuestionario se analizaron mediante métodos de Entropy, WASPAS e interpolación IDW. El análisis resultó en la identificación de 18 reglas distintas para evaluar la calidad de las veredas. Los hallazgos indican que las veredas en la región tres exhiben la más alta calidad, mientras que las de la región siete ocupan el lugar más bajo. En general, el estudio revela que la mayoría de las veredas en Ahvaz son de muy mala calidad, y problemas como pendientes inadecuadas son factores contribuyentes importantes.

Palabras clave: sistemas de inferencia difusa, MATLAB, calidad de veredas, peatones, Ahvaz

Sidewalks and pedestrians are vital components of urban life, playing a crucial role in sustaining the sustainability and livability of cities. High-quality sidewalks contribute to creating safer and more vibrant urban spaces. Given the significant social, economic, and cultural benefits of walking, efforts to improve sidewalk conditions have attracted considerable attention in recent years. This study seeks to evaluate the condition and quality of urban sidewalks in Ahvaz, a city in southwestern Iran. The assessment is based on data collected through questionnaires completed by geography and urban planning experts. A fuzzy inference system implemented in MATLAB software was employed to identify the rules underlying the evaluation of sidewalk quality. Subsequently, the questionnaire data were analyzed using Entropy, WASPAS, and IDW interpolation methods. The analysis resulted in the identification of 18 distinct rules for assessing sidewalk quality. The findings indicate that sidewalks in Region Three exhibit the highest quality, while those in Region Seven rank the lowest. Overall, the study reveals that most sidewalks in Ahvaz are of very poor quality, with issues such as unsuitable slopes being significant contributing factors.

Keywords: fuzzy Inference Systems, MATLAB, Sidewalk Quality, Pedestrians, Ahvaz

USO DE SISTEMAS DE INFERENCIA DIFUSA
PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN
NOORA ABYAT, ZAHRA SOLTANI, MAJID GOODARZI
REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PÁG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

I. INTRODUCTION

Historically, cities were highly pedestrian-friendly, with walking as the primary mode of transportation due to its universal accessibility and affordability. However, a significant modern challenge in urban development is the increasing dependence on motor vehicles, accompanied by the neglect of pedestrian infrastructure and walkways. This shift has been identified as a significant factor in the degradation of urban quality and the erosion of social, cultural, and aesthetic values in public spaces, particularly following the industrial revolution and the advent of car-oriented urban design (Moradpour et al., 2018, p. 212).

Walking remains an economical, healthy, and sustainable mode of transport, profoundly impacting urban life. As the most prevalent form of recreational physical activity, walking improves public health, fosters social connections, and generates significant socioeconomic advantages (Stefanidis & Bartzokas-Tsiompras, 2024, p. 1). Cities that prioritize pedestrianization not only encourage daily physical activity but also reduce public health costs associated with sedentary lifestyles, obesity, and respiratory illnesses (Yussif et al., 2024, p. 1; Zapata-Diomedi et al., 2019; Rundle & Heymsfield, 2016). Walkable neighborhoods are associated with lower obesity prevalence (Kowaleski-Jones et al., 2018, p. 14). Furthermore, pedestrian-friendly urban environments promote mental well-being and environmental sustainability by offering alternatives to car-based commuting (Yussif et al., 2024, p. 1). Many vibrant qualities associated with urban life, such as dynamic street activity, cultural diversity, and opportunities for unexpected interactions, are rooted in high-quality, walkable urban design (Norton, 2011).

With the rise of private cars in the 20th century, cities worldwide began reallocating public urban spaces to accommodate vehicles. This car-centric development has led to widespread "car dependency," contributing to problems such as traffic congestion, fatalities from car accidents, and environmental pollution from noise and emissions (Rhoads et al., 2023, p. 1).

Modern urban design increasingly emphasizes human-centered transportation systems that prioritize public transit, bike lanes, and extensive sidewalk networks over vehicle-oriented infrastructure (Lin et al., 2021, p. 1). In this context, sidewalks should be recognized as foundational elements of urban planning, given their influence on the quality of life, mobility, air quality, and urban design (Da Rocha et al., 2019, p. 42). Beyond facilitating movement, sidewalks serve as spaces for planned and spontaneous social interactions, as well as venues for cultural and commercial activities, including art, music, and business ventures. This multifunctionality highlights their significance in contemporary urban life (Motahari Tabar & Hosseininia, 2022, p. 71).

As vital public spaces, sidewalks foster social connections by shaping the landscapes where meaningful interactions occur. Recognizing the needs of modern society and the intrinsic values of these spaces has driven efforts to design sidewalks that are not only functional but also foster a sense of place and belonging (Ghadami, 2019, p. 950). Sidewalks are purposefully designed for pedestrians and are typically situated alongside streets. Unlike streets or roads, sidewalks are user-centric, designed exclusively to improve pedestrian experiences. They provide safe, accessible pathways while humanizing the streetscape (Li et al., 2024, p. 961). Additionally, sidewalks act as socio-cultural spaces, allowing informal interactions that contribute to preserving cultural identity (Janpathompong & Murakami, 2021, p. 4). High-quality sidewalks encourage pedestrians to walk more, enhancing mobility and sociability (Rachmanto, 2021, p. 6).

As the administrative center of Khuzestan Province and a key industrial hub in southern Iran, Ahvaz experiences high pedestrian density, particularly in its downtown and commercial districts during peak hours. This consistent activity underscores the critical need to assess the quality of the city's sidewalks to support effective urban planning. The present study aims to evaluate the condition and quality of sidewalks in Ahvaz.

II. LITERATURE REVIEW

Zarghami et al. (2015), in their study ***Investigating the Relationship between Urban Pedestrian Pathway Design and Psychological Sense of Security (Case Study: Tehran),*** explored the connection between pedestrians' sense of security and their use of sidewalks.

The results of this study indicated differences between individuals over 40 and under 40 in terms of the extent and reasons for using or not using urban sidewalks. Using a mixed-methods approach, the study revealed that individuals over 40 were more inclined to take short walks than those under 40, who favored vehicles. This disparity underscores a notable behavioral divergence between the two age groups. For both groups, the aesthetic appeal of sidewalks was a key priority. However, older individuals prioritized addressing uneven surfaces, while younger participants expressed greater concern for sidewalk width.

Ekra Sardashti & Sajadzadeh (2021), in their work ***Measuring and Evaluating the Quality of Urban Walkways from the Perspective of the Creative Urban Space: Case Study of Central Urban Walkways in Rasht City of Iran***, assessed the quality of urban sidewalks in Rasht through the lens of creative urban spaces. The study developed a conceptual model of creative urban space and evaluated specific indicators and criteria within this framework. Their findings highlighted that integrating creative city indicators into urban spaces significantly increases citizen satisfaction. Achieving sidewalks that reflect the principles of a creative city necessitates prioritizing the development of these indicators.

Da Rocha et al. (2019), in their article ***Quality of Sidewalks in a Brazilian City: A Broad Vision***, analyzed the quality of sidewalks in a medium-sized Brazilian city by combining pedestrian perceptions with technical evaluations. Their findings revealed that sidewalks in Passo Fundo, similar to those in many Brazilian cities, scored poorly on the Sidewalk Quality Index (SQI). The study emphasized that a high SQI can improve urban mobility and quality of life while positively impacting various urban indicators.

Lee et al. (2009), in their study ***Design Criteria for an Urban Sidewalk Landscape Considering Emotional Perception***, investigated preferences for sidewalk design using affective engineering principles. By modeling the relationships between design elements and their proportions in sidewalk landscapes, the study proposed criteria for designing comfortable and aesthetically pleasing sidewalks. Their results underscored the importance of affective engineering in creating emotionally engaging and visually appealing sidewalk environments.

III. THEORETICAL REVIEW

Roads are a fundamental component of urban outdoor spaces. They serve not only as transportation corridors but also as venues for social interactions and commercial activities. However, with the widespread adoption of personal vehicles and the expansion of urban areas, road design has become increasingly vehicle-centric. Wider lanes and denser road networks have improved traffic flow and efficiency, but this shift has also degraded the quality of urban outdoor environments. Consequently, once vibrant spaces for social and commercial engagement, sidewalks have become constrained by challenges such as air pollution, noise, and thermal stress (Lin et al., 2021, p. 1). Streets are the most extensive public spaces in cities, and sidewalks, as the most frequented areas by pedestrians, play a crucial role in shaping their psychological perceptions (Li et al., 2024, p. 961).

Classic urban theorists such as Jan Gehl and Jane Jacobs have underscored the importance of social, psychological, cultural, and environmental elements in designing walkable spaces. Gehl advocated for cities designed with people, rather than cars, in mind. He emphasized that vibrant urban life relies on fostering meaningful social interactions, creating a sense of safety, and offering an aesthetically pleasing experience through architecture, greenery, and art. Gehl believed that the potential for a lively city is strengthened when more people are invited to walk, bike, and stay in the city's public spaces (Gehl, 2010, p. 6). Jacobs, on the other hand, highlighted the vitality of streets bustling with diverse groups of people throughout the day. Her concept of "eyes on the street" emphasized that active street life naturally increases safety. Jacobs also stressed the significance of mixed land uses, which bring energy and unpredictability to streets, enriching cultural and social interactions while encouraging more pedestrian activity. She contended that sidewalks must sustain consistent foot traffic to not only multiply surveillance but also prompt residents in adjacent buildings to observe street life. As Jacobs (1989, p. 54) noted, "Large numbers of people entertain themselves, off and on, by watching street activity."

In addition to these theoretical contributions, a growing body of research over the past few decades has emphasized the importance of designing pedestrian-friendly streets (Forsyth et al., 2009). The quality of pedestrian networks is increasingly recognized as essential for sustainable urban development and mobility (Forsyth et al., 2009). This involves addressing both tangible and intangible factors, including the physical and built environment (e.g., sidewalk and street widths, tree canopies, population density, building heights, and traffic volumes), urban design attributes (e.g., imageability, legibility, human scale, enclosure, transparency, linkage, and coherence), and human responses (e.g., fear of crime, comfort, and engagement). These factors collectively shape the appeal and functionality of pedestrian spaces but are often overlooked in urban planning and pedestrian accessibility strategies (Stefanidis & Bartzokas-Tsiompras, 2024, p. 1).

Sidewalks are integral elements of streets and serve as dynamic spaces for diverse activities. From a planning perspective, well-designed and integrated sidewalks reflect the city's image. Engaging and thoughtfully planned sidewalks contribute to the perception of a

USO DE SISTEMAS DE INFERENCIA DIFUSA
PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN
NOORA ABYAT, ZAHRA SOLTANI, MAJID GOODARZI
REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PAG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

well-organized city, while poorly designed sidewalks can project an image of disarray (Abdallah, 2020, p. 49).

Deficiencies in sidewalks and restrictions on pedestrian mobility often stem from shortcomings in planning, design, construction, and maintenance (Jia et al., 2022, p. 3). In developing countries, it is common to encounter issues such as poorly designed intersections, missing sidewalk segments, inadequate crossings, limited accessibility for vulnerable users, and deliberate barriers on major roads. Maintenance challenges are also prevalent, with sidewalks frequently overgrown with vegetation, obstructed by debris, or encroached upon by street vendors, parked vehicles, and loading activities. These issues often force pedestrians to engage in risky behaviors, such as walking in traffic lanes or crossing streets at unsafe locations. While road safety initiatives tend to focus on roads and intersections, sidewalk conditions and walkability assessments are often neglected (Jia et al., 2022, p. 3). Similarly, sidewalk maintenance has not received sufficient attention in urban planning and policy discussions, despite its critical role in securing pedestrian safety and comfort (Khalak et al., 2024, p. 455). Pedestrian-oriented design contributes significantly to revitalizing urban centers by creating collective spaces that foster social interactions and solidarity among citizens. Pedestrian areas, as defined by Ghadami (2019, p. 950), are urban spaces where pedestrian movement is prioritized, often by restricting or completely excluding vehicular traffic during specific hours.

Sidewalks are expected to provide six essential benefits for pedestrians: (1) strong connectivity within the path network, (2) integration with public transportation, (3) appealing aesthetics, (4) sufficient safety, (5) fine-grained land use, and (6) high-quality pedestrian paths (Yencha, 2019, p. 690). These factors are evaluated through two primary categories: neighborhood-level (macroscale) and sidewalk-level (microscale) features. Neighborhood-level features include environmental elements such as land-use diversity, aesthetics, dwelling and intersection density, and street connectivity. In contrast, sidewalk-level features focus on infrastructure-specific characteristics, including surface conditions, width, furniture, and curbs. These microscale features directly impact pedestrian comfort and satisfaction. However, continuous use and adverse environmental conditions often deteriorate infrastructure, making timely maintenance crucial for optimal functionality (Yussif et al., 2024; p. 2).

The "Five Cs" approach is a comprehensive framework for improving streets and sidewalks by prioritizing walkability and accommodating diverse activities. This approach emphasizes meeting pedestrians' needs, both for formal and informal activities, and outlines five critical principles for enhancing the walking experience:

- Connected: Establishing a complete network of routes and sidewalks, both at a macroscale (street connectivity) and microscale (physically or visually linked sidewalks).
- Convivial: Structuring sidewalks to facilitate social interactions by meeting users' needs in an organized and inclusive way, creating safer, more pleasant, and comfortable spaces.
- Conspicuous: Providing clear signage for streets, shops, and sidewalk activities to facilitate accessible, smooth, and enjoyable walking experiences.
- Comfortable: Incorporating amenities like seating, shading devices, and regular pavement maintenance to increase comfort.
- Convenient: Designing sidewalks and streets to be efficient, cost-effective, and user-friendly, catering to pedestrians' functional and aesthetic needs.

By applying these principles, sidewalks can support a diverse range of activities while protecting pedestrian safety and comfort. Achieving this requires aligning activity patterns with these principles and understanding the relationship between usage patterns and walkability (Abdallah, 2020, p. 59).

The focus on improving sidewalks is not new, but has evolved significantly in recent decades. Jane Jacobs, in her influential work since the 1960s, introduced the concept of "eyes on the street," emphasizing the role of diverse street users in providing natural surveillance and enhancing safety. Jacobs (1989, p. 56) articulated this concept with particular insight regarding sidewalk security, noting the necessity for "an almost unconscious assumption of general street support when the chips are down" among those providing this surveillance. She succinctly encapsulated this phenomenon as "trust" - a social construct that emerges gradually through countless minor interactions in public sidewalk spaces. This concept highlights how homemakers, shopkeepers, pedestrians, street vendors, and office workers collectively create a sense of security for all users. Subsequent theories by urban designers and architects have underscored the benefits of walking and sidewalk use, including reduced reliance on motor vehicles, lower transport emissions, and improved public health (Mozingo, 1989; Smith & dos Santos, 2019). Increased pedestrian activity also leads to safer streets, greater urban vibrancy, and improved social cohesion.

Index	Indicator	Index	Indicator	Index	Indicator
I1	Safety	I6	Vitality	I11	Maintenance
I2	Security	I7	Flooring	I12	Cleanliness
I3	Lighting	I8	Accessibility	I13	Proper slope
I4	Green space	I9	Cohesiveness	I14	Proper width
I5	Mobility	I10	Social interaction	I15	Suitable for all groups of life

Table 1. Sidewalk Quality Indicators. Source: Preparation by the Authors.

The importance of sidewalks has gained renewed attention in urban design, particularly in the post-pandemic era. Many cities have developed guidelines and principles to improve sidewalk livability and sustainability, focusing on factors such as universal accessibility, safe connections, signage, aesthetics, security, quality surfaces, and proper drainage. Sidewalks must extend their functions beyond providing circulation spaces to fostering direct contact between citizens and their social environments.

Accordingly, five basic criteria have been identified for effective sidewalk design:

a. Accessibility: Guaranteeing all individuals, including those with mobility challenges, can use sidewalks safely and independently. This includes providing comfort, shelter, and protection while adhering to principles of broad access and ease of movement.
b. Maintenance: Addressing the physical condition of pavement, covering materials, and floor adhesion to guarantee pedestrian comfort and safety.
c. Connectivity: Establishing continuous routes free from obstacles, with level crossings, appropriate signage, and accessibility features that accommodate diverse needs.
d. Security: Improving both real and perceived safety through adequate lighting, the presence of other pedestrians, and urban infrastructure designed to minimize risks.
e. Ambience: Integrating landscaping elements and design features that enhance sidewalks' usability and visual appeal (Almeida et al., 2024, p. 729).

A well-connected sidewalk network is essential for promoting pedestrian mobility, improving accessibility, and fostering sustainable, pedestrian-friendly urban environments (Quijada-Alarcón et al., 2024; p. 2).

IV. MATERIALS AND METHODS

This research employed a descriptive-analytical and applied approach regarding content and methodology. Data and information were collected using a documentary field survey method. Indicators for assessing urban sidewalk quality were derived from a comprehensive review of the theoretical literature (Table 1).

The statistical population consisted of geography and urban planning experts. A sample of 10 experts participated in a questionnaire-based survey to evaluate the quality of sidewalks in various regions of Ahvaz. Their responses formed the foundation for the research analysis.

To analyze the data, several methodologies were employed:

- The fuzzy inference system in MATLAB software was used to establish the rules for measuring sidewalk quality.
- The Entropy method was applied to weigh the indicators.
- The WASPAS model was employed to rank the regions of Ahvaz based on sidewalk quality.
- The Inverse Distance Weighting (IDW) interpolation method was employed to visualize the condition of sidewalks in Ahvaz.

Research study area

Ahvaz is one of the largest cities in Iran and serves as the country's primary financial hub (Pakbaz et al., 2013, p. 109). It is the capital city of Khuzestan province and is strategically located along the Karun River, one of the country's major rivers. Situated in an oil-rich province bordering Iraq and Kuwait, Ahvaz holds a significant geopolitical position (Alizadeh & Sharifi, 2020, p. 7). The city is surrounded by

USO DE SISTEMAS DE INFERENCIA DIFUSA
PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN
NOORA ABYAT, ZAHRA SOLTANI, MAJID GOODARZI
REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PAG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

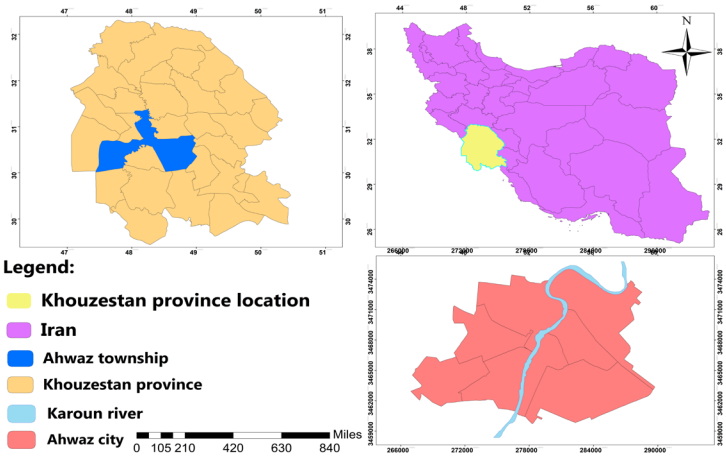

Figure 1. Study area. Source: Preparation by the Authors.

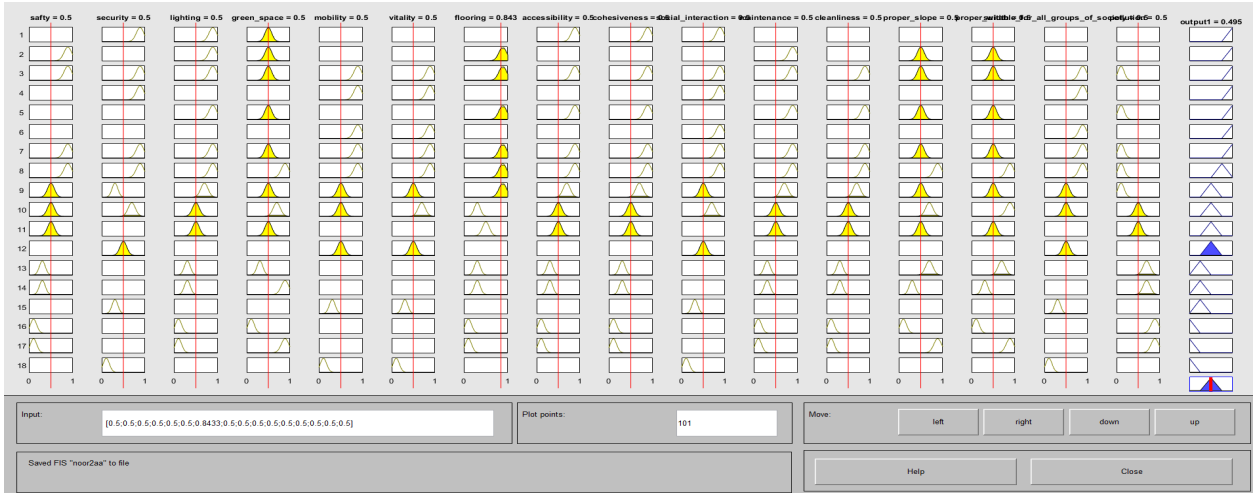

Figure 2. Fuzzy inference system output rules. Source: Preparation by the Authors.

Sheiban, Veis, Mollasani, Shooshtar, Dezful, and Shoosh to the north, Ramhormoz to the east, Hamidieh to the west, and Shadegan, Mahshahr, Khoramshahr, and Abadan to the south.

Ahvaz is divided into eight urban regions, each consisting of three or four districts (Safaeepour et al., 2017, p. 6). The geographical coordinates of Ahvaz are 31°20′N and 48°40′E (Figure 1), with an elevation of 18 meters above sea level. The city's industrial sector, including numerous large industrial plants, has made Ahvaz one of Iran's key industrial centers, attracting many immigrants to the area (Alavi et al., 2015, p. 299). Covering an area of approximately 220 km^2, Ahvaz has a population of nearly 1.2 million people.

V. ANALYSIS OF FINDINGS

Initially, the fuzzy inference system model was implemented, and 18 rules were extracted to measure the quality of urban sidewalks based on the research indicators. The rules are as follows (Figure 2):

- Rule 1: If security, lighting, accessibility, cohesiveness, and social interaction are very high, and green space is average, then the quality of sidewalks will be very high.
- Rule 2: If safety, lighting, flooring quality, and social interaction are very high, and green space, proper

width, and proper slope are average, then the quality of sidewalks will be very high.

- Rule 3: If safety, security, lighting, mobility, vitality, suitable flooring, accessibility, cohesiveness, and social interaction are very high, and green space, proper width, and proper slope are average, then the quality of sidewalks will be very high.
- Rule 4: If security, lighting, mobility, vitality, social interaction, and suitability for all groups of society are very high, then the quality of sidewalks will be very high.
- Rule 5: If lighting, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are very high, and green space is average, then the quality of sidewalks will be very high.
- Rule 6: If mobility, vitality, social interaction, and suitability for all sections of society are very high, then the quality of sidewalks will be very high.
- Rule 7: If safety, security, lighting, mobility, vitality, appropriate flooring, accessibility, cohesiveness, social interaction, maintenance, cleanliness, and suitability for all sections of society are very high, and green space, proper slope, and proper width are average, then the quality of sidewalks will be very high.
- Rule 8: If safety, security, lighting, mobility, vitality, suitable flooring, accessibility, cohesiveness, social interaction, maintenance, cleanliness, and suitability for all sections of society are very high, and green space, and proper width and slope are high, then the quality of sidewalks will be relatively high.
- Rule 9: If lighting, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are very high, and safety, green space, mobility, vitality, social interaction, proper slope, proper width, and suitability for all sections of society are average, and security is low, then the quality of sidewalks will be average.
- Rule 10: If safety, mobility, accessibility, cohesiveness, maintenance, cleanliness, and suitability for various groups of society are high, and security, green space, vitality, social interaction, proper slope, and proper width are high, and the quality of flooring is low, then the quality of sidewalks will be average.
- Rule 11: If safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, cleanliness, proper slope, and proper width are average, then the quality of sidewalks will be almost average.
- Rule 12: If security, mobility, vitality, social interaction, and suitability for all groups of society are average, then the quality of sidewalks will be almost average.
- Rule 13: If proper slope and width are high, and safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are low, then the quality of sidewalks will be low.

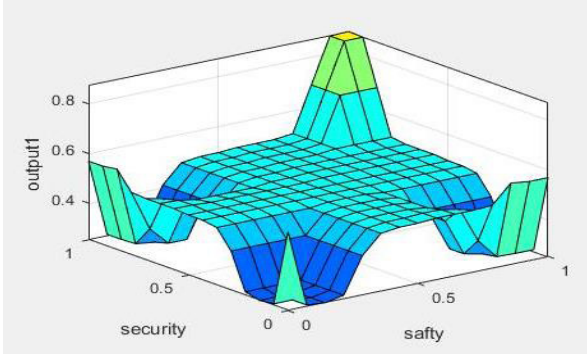

Figure 3. Output diagram of the rules of the fuzzy inference system. Source: Preparation by the Authors.

- Rule 14: If green space is too high, and safety, lighting, suitable flooring, accessibility, cohesiveness, maintenance, cleanliness, proper slope, and proper width are low, then the quality of sidewalks will be low.
- Rule 15: If green space is too high, and security, mobility, vitality, appropriate flooring, social interaction, and suitability for all groups of society are low, then the quality of sidewalks will be low.
- Rule 16: If safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, cleanliness, proper slope, and proper width are too low, then the quality of sidewalks will be too low.
- Rule 17: If green space, proper slope, and proper width are too high, and safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are too low, then the quality of sidewalks will be too low.
- Rule 18: If safety, mobility, vitality, social interaction, and suitability for all groups of society are too low, then the quality of sidewalks will be too low.

Eventually, the following figure illustrates the output diagram generated by the fuzzy inference system, showing the rules' results. (Figure 3)

Subsequently, the condition of urban sidewalks in various regions of Ahvaz was assessed. A questionnaire was distributed to experts, who provided their evaluations of sidewalk quality based on the city's zoning. The average of their responses was then calculated and analyzed. Shannon's Entropy Model was applied to determine the weight of the indicators. The results of this model, showing the weights assigned to each indicator, are presented in Table 2 below for further analysis in the subsequent stages.

index	Safety	Security	Lighting	Green space	Mobility
w	0.0666	0.0668	0.0673	0.0665	0.0670
index	Vitality	Flooring	Accessibility	Cohesiveness	Social interaction
w	0.0669	0.0664	0.0671	0.0665	0.0673
index	Maintenance	Cleanliness	Proper slope	Proper width	Suitable for all groups of life
w	0.0655	0.0665	0.0662	0.0664	0.0671

Table 2. Weights of Indexes. Source: Preparation by the Authors.

Then, the results of the experts' questionnaire, along with the weights of the indicators obtained in the previous step, were entered into Excel software to determine the regions' ranking according to the quality of the sidewalks using the WASPAS model. A numerical value was obtained for each region, and its corresponding rank was determined, as shown in Table 3.

This table illustrates the regions' ranking, with Region Three having the highest sidewalk quality score (0.929) and Region 7 having the lowest (0.454).

The outcomes of the previous steps were entered into the GIS software to illustrate the current situation clearly. Using the IDW interpolation model, the general outline of sidewalk quality across the regions was depicted (Figure 4).

By analyzing the results of the WASPAS and IDW models, it was found that Region Three has the highest quality of urban sidewalks compared to other regions (Figure 5). The sidewalks in this area stand out for their superior safety levels. Security is consistently high across most sidewalks in the region. Additionally, Region Three boasts ample green space, well-maintained flooring, appropriate slope, and a high degree of cohesiveness. Regular maintenance guarantees the sidewalks are well-kept. These factors make the sidewalks in this region accessible to diverse social groups and promote social interactions. However, accessibility remains a challenge in some neighborhoods within the region.

Región	Q2	Rank
1	0,608	4
2	0,820	2
3	0,929	1
4	0,738	3
5	0,575	5
6	0,460	7
7	0,454	8
8	0,558	6

Table 3. Rankings of regions based on sidewalk quality. Source: Preparation by the Authors.

Region Two ranks second (Figure 6). The vitality and mobility of the sidewalks here are higher than those in other regions. Safety is also a strong feature in most areas, with well-maintained sidewalks that cater to a wide range of users. These elements together boost social interaction. However, security is a notable concern, as certain sidewalks in this region suffer from lower security levels.

Region Four ranks third (Figure 7). The sidewalks in this region are particularly distinguished by their high accessibility, which is the best in the city. Additionally, most sidewalks here have optimal width. Social interaction is prevalent along many of these sidewalks, and mobility and safety levels are relatively high. However, there are two significant issues: the severe lack of lighting and the pressing need for improved green spaces. Moreover, maintenance is inadequate in some parts of the region, further affecting sidewalk quality.

USO DE SISTEMAS DE INFERENCIA DIFUSA
PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN
NOORA ABYAT, ZAHRA SOLTANI, MAJID GOODARZI
REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PÁG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

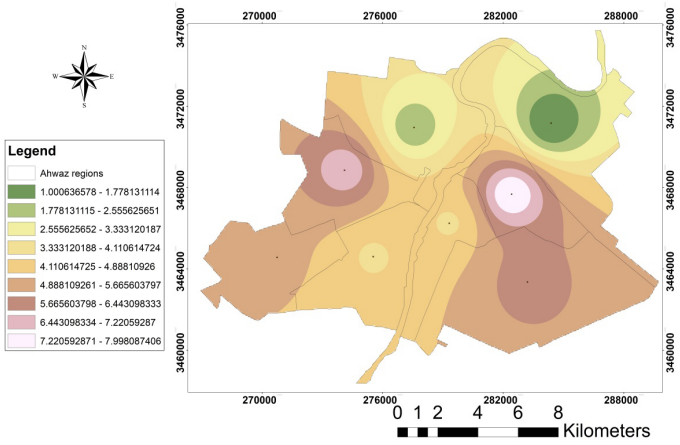

Figure 4: Sidewalk quality IDW. Source: Preparation by the Authors.

Figure 5: Sidewalk in Region Three. Source: Photo taken by the Authors.

Figure 6: Sidewalk in Region Two. Source: Photo taken by the Authors.

USO DE SISTEMAS DE INFERENCIA DIFUSA
PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN
NOORA ABYAT, ZAHRA SOLTANI, MAJID GOODARZI
REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PÁG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

Region One ranks next in the overall ranking (Figure 8). The sidewalks exhibit exceptionally high mobility and vitality, significantly improving social interactions. These sidewalks are generally suitable for use by diverse social groups. However, they lack proper slope and width, and the flooring is often inadequate. Insufficient lighting is another issue in this region. There is a pressing need for increased green space and more frequent maintenance to improve the quality of the sidewalks.

Region Five is ranked fifth (Figure 9). The sidewalks in this region score poorly across several indicators. While some sidewalks have nearly adequate width, the overall quality remains low. Social interaction is relatively high in certain areas, but security is a significant concern, as most sidewalks in this region have very low security. The flooring is frequently unsuitable, and maintenance is irregular.

Figure 7: Sidewalk in Region Four. Source: Photo taken by the Authors

Figure 8: Sidewalk in Region One. Source: Photo taken by the Authors

Furthermore, the sidewalks suffer from poor lighting and a lack of green space. Vitality and accessibility are low, and many areas are plagued by improper slope and weak cohesiveness.

Region Eight follows closely behind (Figure 10). While certain sidewalks in this region demonstrate high social interaction, overall, the quality is low. Cleanliness is only moderately acceptable, and cohesiveness is lacking. Accessibility is low, and the sidewalks do not cater well to the needs of different social groups, which limits social interaction. As a result, vitality and mobility are also low. Many of the sidewalks here are hindered by improper width, slope, lighting, and insufficient green space. Safety and security are significant concerns, and maintenance is insufficient.

Region Six is next in the ranking (Figure 11). The sidewalks here perform well only in terms of social interaction, which slightly boosts the area's vitality. However, they are lacking in many other key indicators. The sidewalks are too narrow and have improper slopes, leading to poor accessibility. Safety and security are minimal, and green space is extremely limited. Cleanliness and maintenance are largely neglected, making the sidewalks unsuitable for the community.

Region Seven is ranked lowest (Figure 12). The sidewalks here perform poorly in all the indicators studied. They are notably lacking in safety, with issues such as unsuitable slopes, insufficient width, and inadequate green space being particularly problematic. Lighting and flooring are also substandard. Security is low across the region, making

USO DE SISTEMAS DE INFERENCIA DIFUSA
PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN
NOORA ABYAT, ZAHRA SOLTANI, MAJID GOODARZI
REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PÁG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

Figure 9: Sidewalk in Region Five. Source: Photo taken by the Authors

Figure 10: Sidewalk in Region Eight. Source: Photo taken by the Authors

Figure 11: Sidewalk in Region Six. Source: Photo taken by the Authors

Figure 12: Sidewalk in Region Seven. Source: Photo taken by the Authors

USO DE SISTEMAS DE INFERENCIA DIFUSA
PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN
NOORA ABYAT, ZAHRA SOLTANI, MAJID GOODARZI
REVISTA URBANO Nº 51 / MAYO 2024 - OCTUBRE 2025
PAG. 60 - 73
ISSN 0717 - 3997 / 0718 - 3607

the sidewalks unsuitable for a wide range of users. The vitality and mobility of these sidewalks are consistently low, and maintenance and cleanliness are neglected, further diminishing their quality.

VI. CONCLUSION

Sidewalks are undeniably one of the most critical components of urban infrastructure. They not only facilitate pedestrian movement but also contribute significantly to the vitality of public spaces, symbolizing a city's identity, civility, and quality of life. Although the importance of improving sidewalks is not new, it has gained heightened attention in recent decades, particularly in the wake of the COVID-19 pandemic. The post-pandemic period witnessed heightened attention to urban infrastructure modifications, particularly the widening of walkways and pedestrian paths to improve pedestrian safety and comfort. Furthermore, the increased preference for sidewalk usage over public transportation, driven by their open-air nature and reduced interpersonal contact, has significantly amplified the focus on improving pedestrian infrastructure quality during this era.

This shift has led many cities to adopt guidelines and principles to create more livable and sustainable pedestrian areas, fostering vibrant and active urban spaces.

In Ahvaz, particularly within its administrative and commercial centers, high population densities during peak hours underscore the need for comprehensive research to evaluate and improve sidewalk quality. This study sought to assess the condition of sidewalks across the city's regions using a combination of documentary and field survey methods. Data were gathered through a structured questionnaire distributed to geography and urban planning experts, providing the basis for measuring sidewalk quality.

The study employed a fuzzy inference system in MATLAB software to analyze the data and create quality measurement rules. Shannon's Entropy was used to assign weights to different indicators, and the WASPAS model was used to rank the city's regions based on sidewalk quality. The findings reveal several critical issues with Ahvaz's sidewalks. A prominent weakness is the prevalence of improper slopes, which frequently renders sidewalks impassable during the rainy season. Additionally, inadequate flooring poses challenges for pedestrians, particularly for individuals with disabilities. Many sidewalks lack sufficient lighting and green spaces, while safety and security remain pressing concerns.

Despite these challenges, the study highlights a notable strength: Ahvaz's sidewalks support relatively high levels of social interaction, which boosts their vitality and mobility to some extent. However, this strength is overshadowed by the need for significant improvements in maintenance, cleanliness, and overall accessibility. Addressing these deficiencies through strategic urban planning and targeted interventions will not only improve the quality of Ahvaz's sidewalks but also enhance the livability and functionality of its urban spaces for all residents. To improve the quality of sidewalks in Ahvaz, urban planning efforts must prioritize specific issues that are currently inadequate across most areas of the city. One critical measure is expanding green spaces and vegetation along sidewalks, using native plant species to guarantee sustainability. Additionally, waste management must be prioritized citywide, as environmental pollution significantly disrupts the usability of these spaces. Attention to urban street furniture, such as benches and shade structures, can further improve pedestrian comfort by providing resting areas. Moreover, revitalizing Ahvaz's streetscapes through aesthetic improvements and promoting group activities, including cultural and artistic events, would inject much-needed vibrancy into the city. Despite being essential for urban vitality, such activities are currently scarce in Ahvaz. Finally, practical concerns, such as proper slope adjustments, durable pavement materials, and adequate lighting, must be implemented consistently across all districts. Adopting these measures would substantially elevate the quality of sidewalks throughout Ahvaz.

VII. CONTRIBUTION OF AUTHORS CRediT.

Conceptualization, M.G.; Data curation, M.G.; Formal analysis, M.G. & Z.S.; Acquisition of financing, N.A. & Z.S.; Research, M.G., Z.S. & N.A.; Methodology, M.G. & N.A.; Project management, M.G.; Resources, Z.S. & N.A.; Software, M.G.; Supervision, M.G.; Validation, Z.S. & N.A.; Visualization, N.A.; Writing – original draft, M.G. & N.A; Writing – revision and editing, M.G. & Z.S.

VIII. REFERENCES

Abdallah, D. A. A. (2020). *Sidewalks informality: Impacts of transgressive informal practices on people's perceived walkability. The case of Downtown, Cairo in time of a pandemic* [Tesis de Magíster, Universidad Ain Shams, Egipto]. Sistema Shams de tesis universitarias. https://iusd.asu.edu.eg/wp-content/uploads/2021/06/MSC-Sidewalks-informality-Dina-Alaa-Ali_compressed-1.pdf

Alavi, N., Shirmardi, M., Babaei, A., Takdastan, A., y Bagheri, N. (2015). Waste electrical and electronic equipment (WEEE) estimation: A case study of Ahvaz City, Iran. *Journal of the Air & Waste Management Association, 65***(3), 298–305.** https://doi.org/10.1080/10962247.2014.976297

Alizadeh, H., y Sharifi, A. (2020). Assessing resilience of urban critical infrastructure networks: A case study of Ahvaz, Iran. *Sustainability, 12***(9),** 3621. https://doi.org/10.3390/su12093691

Almeida, R. A. de, Hardt, L. P. A., y Hardt, C. (2024). Sidewalks as places for socialization: Urban equity for people with reduced mobility. *Cadernos Metrópole, 26*(60), 727–755. https://doi.org/10.1590/2236-9996.2024-6015

Ekra Sardashti, A., y Sajadzadeh, H. (2021). Measuring and evaluating the quality of urban walkways from the perspective of the creative urban space, Case study: Central urban walkway in Rasht city of Iran. *Armanshahr Architecture and Urban Development, 14*(34), 169–181. https://doi.org/10.22034/aaud.2020.202474.2006

Forsyth, A., Michael Oakes, J., Lee, B., y Schmitz, K.H. (2009). The Built Environment, Walking, and Physical Activity: Is the Environment More Important to Some People than Others? *Transportation Research Part D: Transport and Environment, 14*(1), 42–49. https://doi.org/10.1016/j.trd.2008.10.003

Gehl, J. (2010). Cities for People; *Island Press: Washington, DC, USA*, 269 p.

Ghadami, S. (2019). Investigating the functional role of sidewalks in promoting social interactions (Case study: Aminolmolk Street in Tehran). *International Journal of Engineering and Technology, 11*(4), 950–959. https://doi.org/10.21817/ijet/2019/v11i4/191104076

Jacobs, J. (1989). The death and life of great American cities. *Random House*. 458 p.

Janpathompong, S., y Murakami, A. (2021). Understanding Thai urban pedestrian culture during noon break: How sidewalk users experience the walking infrastructure in Bangkok, Thailand. *Nakhara: Journal of Environmental Design and Planning, 20*(3), 115. https://doi.org/10.54028/NJ202120115

Jia, W., Fantta, B.T., y Alcalá, Y. M. (2022). Addis Ababa Sidewalk Safety and Improvement Study. *Washington, DC: Banco Mundial*. 72. https://documents1.worldbank.org/curated/en/099427403282212415/pdf/IDU016981078031bd04bce0b83202391d87a8a9a.pdf

Khalak, A. A., Hussen, M., Ahmed, S., y Pandya, T. (2024). Pedestrian safety at signalized intersections in developing countries: A critical appraisal. *International Journal of Research Publication and Reviews, 5*(2), 454–457. https://doi.org/10.55248/gengpi.5.0224.0413

Kowaleski-Jones, L., Zick, C., Smith, K. R., Brown, B., Hanson, H., y Fan, J. (2018). Walkable neighborhoods and obesity: Evaluating effects with a propensity score approach. *SSM - Population Health, 6*, 9–15. https://doi.org/10.1016/j.ssmph.2017.11.005

Lee, B. J., Jang, T. Y., Wang, W., y Namgung, M. (2009). Design criteria for an urban sidewalk landscape considering emotional perception. *Journal of Urban Planning and Development, 135*(4). https://doi.org/10.1061/(ASCE)UP.1943-5444.0000013

Li, Y., Li, M., Xu, Y., y Tao, J. (2024). "Interface-element-perception" model to evaluate urban sidewalk visual landscape in the core area of Beijing. *Frontiers of Architectural Research, 13*(5), 960–977. https://doi.org/10.1016/j.foar.2023.12.006

Lin, B.-S., Cho, Y.-H., y Hsieh, C.-I. (2021). Study of the thermal environment of sidewalks within varied urban road structures. *Urban Forestry & Urban Greening, 62*, 127137. https://doi.org/10.1016/j.ufug.2021.127137

Motahari Tabar, M., y Hosseininia, M. (2022). Investigating the policies of the impact of sidewalks on the quality of housing (Case study of Bu Ali sidewalk in Hamedan). *Journal of Urban Environmental Planning and Development, 2*(5), 73–86. https://sid.ir/paper/1022289/en

Moradpour, N., Poorahmad, A., y Hataminejad, H. (2018). A comparative study of development indicators of walking in Tehran (Case study: neighborhood Amirabad and Tehran University). *Geographic Space, 18*(62), 211–235. https://sid.ir/paper/91717/en

Mozingo L. (1989). Women and downtown open spaces. *Places*, *6*(1), 38-47. https://escholarship.org/uc/item/7jd71866

Norton, P. D. (2011). Fighting traffic: The dawn of the motor age in the American city. *MIT Press.*

Pakbaz, M. S., Imanzadeh, S., y Bagherinia, K. H. (2013). Characteristics of diaphragm wall lateral deformations and ground surface settlements: Case study in Iran—Ahvaz metro. *Tunnelling and Underground Space Technology, 35*, 109–121. https://doi.org/10.1016/j.tust.2012.12.008

Quijada-Alarcón, J., Rodríguez-Rodríguez, R., Icaza, A., González-Cancelas, N., y Bethancourt-Lasso, G. (2024). Social perception of the connectivity and quality of sidewalks in the Metropolitan Area of Panama. *Journal of Maps*, *20*(1), 2349167. https://doi.org/10.1080/17445647.2024.2349167

Rachmanto, A. S. (2021). The appropriation of sidewalks for e-scooter use: From the urban built environment perspective. *Smart City, 1*(1), 1–15. https://doi.org/10.56940/sc.v1.i1.6

Rhoads, D., Rames, C., Solé-Ribalta, A., González, M. C., Szell, M., y Borge-Holthoefer, J. (2023). Sidewalk networks: Review and outlook. *Computers, Environment and Urban Systems, 106*, 102031. https://doi.org/10.1016/j.compenvurbsys.2023.102031

Da Rocha, V. T., Brandli, L. L., Kalil, R. M. L., Salvia, A. L., y Prietto, P. D. M. (2019). Quality of sidewalks in a Brazilian city: A broad vision. *Theoretical and Empirical Research in Urban Management, 14*(2), 41–58. https://um.ase.ro/v14i2/3.pdf

Rundle, A. G., y Heymsfield, S. B. (2016). Can Walkable Urban Design Play a Role in Reducing the Incidence of Obesity-Related Conditions? *JAMA*, *315*(20), 2175–2177. https://doi.org/10.1001/jama.2016.5635

Safaeepour, M., Maleki, S., Hataminejad, H., y Modanlou, M. (2017). Evaluation of city prosperity index in Iranian-Islamic cities: A case study of Ahvaz Metropolis. *Chinese Journal of Urban and Environmental Studies, 5*(4), 1750025. https://doi.org/10.1142/S2345748117500257

Smith, H., y dos Santos, P. M. (October 8, 2019). *8 principles to better sidewalks*. Complete Streets, TheCityFix. https://thecityfix.com/blog/8-principles-better-sidewalks-hillary-smith-paula-manoela-dos-santos/

Stefanidis, R.-M., y Bartzokas-Tsiompras, A. (2024). Pedestrian accessibility analysis of sidewalk-specific networks: Insights from three Latin American Central Squares. *Sustainability, 16*(21), 9294. https://doi.org/10.3390/su16219294

Yencha, C. (2019). Valuing walkability: New evidence from computer vision methods. *Transportation Research Part A: Policy and Practice, 130*, 689–709. https://doi.org/10.1016/j.tra.2019.09.053

Yussif, A.-M., Zayed, T., Taiwo, R., y Fares, A. (2024). Promoting sustainable urban mobility via automated sidewalk defect detection. *Sustainable Development, 32*(5), 5861-5881. https://doi.org/10.1002/sd.2999

Zapata-Diomedi, B., Boulangé, C., Giles-Corti, B., Phelan, K., Washington, S., Veerman, J. L., y Gunn, L. D. (2019). Physical activity-related health and economic benefits of building walkable neighbourhoods: a modelled comparison between brownfield and greenfield developments. *International Journal of Behavioral Nutrition and Physical Activity, 16*, 11. https://doi.org/10.1186/s12966-019-0775-8

Zarghami, E., Ajdahfar, Sh., y Todehfallah, S. (2015). *Investigating the relationship between urban pedestrian design and feeling of psychological Safety (Case study: Tehran).* The First National Conference on Geography, Urban Planning and Sustainable Development, Tehran. https://civilica.com/doc/266884