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ENHANCING PEDESTRIAN SAFETY THROUGH ENVIRONMENTAL ANALYSIS: A CASE STUDY OF SANG-E SIAH STREET, SHIRAZ

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Abstract. Promoting walkability in urban areas has emerged as a critical objective for urban designers worldwide due to its positive impacts on public health, local businesses, and the environment. However, pedestrian safety remains a significant concern, particularly in downtown areas. This study evaluates environmental factors' influence on pedestrian safety, with a specific case study of Sang-e-Siah Street in Shiraz. The research adopts a remote analysis approach utilizing on-site photographs and Google Earth maps to assess the urban environment along the street. The street is divided into three sections to evaluate and compare the environmental factors in each segment. Key indicators considered are land uses, sidewalk and road conditions, accessibility, and other relevant elements evaluated on a three-tier scale: high, medium, and low impact. By examining the environmental factors qualitatively, their impact on pedestrian safety is assessed in each section. The study identifies variations in the significance of each factor across different segments of the street. Some elements exhibit varying degrees of impact, while others demonstrate negligible influence. Through this qualitative comparison, the research aims to present comprehensive findings that enable a better evaluation of the three sections based on observations and reports. The study's outcomes can guide urban planners and policymakers in making informed decisions to improve pedestrian safety and enhance the overall walkability of Sang-e-Siah Street and similar urban corridors.

Keywords: Walkability, Pedestrian Safety, Pedestrian Safety Indicators, Environmental Factors

Introduction. People who use public transport or private cars must still walk a substantial distance to get to their vehicle or the transit stop. Additionally, It is one of the main transport modes for most urban poor people in Asian cities (Tiwari, G., 2001), Including Iran. Approximately more than half of the world's population resides in urban areas. Thus, pedestrian safety is a concern not only in cities but also in any urban setting. With increased movement and motorization, pedestrians are more likely to be on the roads, emphasizing the importance of ensuring their safety(Stroker P. et al., 2015, p. 4). Of the more than one million annual road traffic deaths, nearly a quarter (22%) are

other pedestrians, 5% cyclists, 23% motorcyclists, 31% car occupants, and 19% groups or unspecified (World Health Organization 2013a).

The physical context of pedestrian safety is the environment, the focus of this article. Several of the mentioned injuries are related to the environment: buffers and barriers, land uses, poor lighting, and other items which affect pedestrian safety. All environments are not equally safe because the existence and different characteristics can reduce or increase the security of pedestrians(Ding C. et al., 2018).

Thus we need to recognize what risks to pedestrians result from the environment and how they affect it. In the context of Shiraz, many streets and allies of the historical district lack consideration for pedestrian safety and provide low levels of pedestrian service. Sang-e-Siah's Street is an exceptional example that shows the potential for improvement in that regard. Thus it has been studied to examine the strengths and weaknesses of pedestrian safety in a mixed street to answer the question: How does the environment affect pedestrian safety in Sang-e-Siah?

Statement of The Problem. Despite all of the benefits of walking, vulnerable road users (VRUs) and particularly pedestrians are at a potential disadvantage and have no rigid protection against road traffic (Ahmed, T. et al., 2021:1). That results in 275,000 Pedestrian annual deaths according to WHO report on global road safety. The report indicates that pedestrians and cyclists represent 26% of fatal road traffic crashes worldwide. Increasing sustainable transport modes, such as walking, is one of the essential strategies for reducing vehicular traffic in urban areas (Eboli, L. et al., 2023:1).

In 2016, according to the communication agency of transportation and traffic in Shiraz municipality, Shiraz and its providence (Fars) ranked first regarding the number of casualties in car accidents, and among 200 annual deaths in fatal crashes, 51% of them consist of pedestrians (Tabnak, 2016). In 2021, roughly 46% of deaths in fatal crashes were pedestrians from March to September. The national percentage of pedestrian deaths involving car accidents is between 25 to 30% (Shiraze, 2021). According to these statistics, Shiraz can be considered one of the cities for walking, and it will be necessary to investigate the reasons for the lack of safety for pedestrians.

Literature review. Pedestrians are considered among the most vulnerable road users due to their higher fatality rates than car occupants and other road users. Therefore, the influential factors affecting pedestrian safety have been widely investigated. Pedestrian safety can be affected by various factors. However, they can be categorized into three main groups, 1) Traffic characteristics, 2) Demographic characteristics, 3) Environmental Factors (Zhu, M. et al., 2022:2). Due to the diversity of the factors involved and to provide a more in-depth evaluation of pedestrian safety, this research focuses only on the relationship between pedestrian safety and environmental factors (Zhu, M. et al., 2022:2).

Stoker (2015) has reviewed the design of roadway and its contribution to pedestrian safety as part of the built environment and, in conclusion, divided the design treatments into two main categories: 1) measures that reduce traffic volume or reduce pedestrian exposure to crash, such as sidewalk and footpaths, marked crossings, overpass and underpasses and mass transit routes. 2) speed management treatments that reduce vehicular speed by either a) forcing drivers into turning right and left or b) forcing them into changing their elevation. Moreover, their extensive review concluded that both goals are achievable by reducing the width of the road, and the safest roads are as narrow as 7.3 m wide (or 24 ft).

Asadi-Shekari (2015) developed a comprehensive pedestrian safety index by reviewing 20 guidelines from various countries and summarized them into 24 indicators. These indicators consist of (1) slower traffic speed, (2) buffers and barriers (curb and furnishing zone), (3) fewer traffic lanes, (4) shorter crossing distance (curb extension), (5) mid-block crossing, (6) landscape and trees, (7) footpath pavement, (8) marking (crosswalk), (9) pedestrian refuge and median, (10) corner island, (11) sidewalk on both sides, (12) advance stop bar, (13) driveway, (14) lighting, (15) signing, (16) bollard, (17) slope, (18) lift, (19) curb ramp, (20) tactile pavement (guiding),(21) tactile pavement (warning), (22) ramp, (23) grade, and (24) signal.

Osama (2017) Claims that commercial area density is positively associated with pedestrians' exposure to accidents. However, increased recreational and residential land use can reduce that risk. The link between recreational land use and pedestrian safety is justified by the off-street continuous paths provided by parks which ultimately reduce the risk of conflict for vulnerable road users. This is consistent with Ukkusuri's (2011) work which confirms the positive effect of recreational land use on pedestrian safety, and also confirmed by Kim's (2019) study, which mentioned the role of parks and recreational land uses in improving elderly pedestrian safety. On the other hand, Heydari (2020) has proven that approximately two school areas deteriorated pedestrian safety.

Zhu's (2022) Findings are evidence of the positive effects of street trees on pedestrian safety. According to their data, urban forests are associated with lowering the risk of injuries and fatalities in accidents. They create a visual wall that keeps the driver's focus on the road and buffers the pedestrian path from the roadway. Kim (2019) also reported that street trees improved the safety of elderly pedestrians.

Speed humps and raised crosswalks are environmental features that Stoker (2015) considers as measures that can be applied to reduce vehicular speed and traffic volume. Moreover, in a case study conducted in Belgium, Spain, Cafiso et al. (2010) witnessed a significant reduction in pedestrian risk index values when a combination of the hump and raised crosswalk was applied in comparison to standard zebra crosswalks (Obeid, H. et al., 2017:57).

Stipancic (2021) stated that stop signs are responsible for a significant reduction in the approach speed of vehicles. However, there is no evidence of their effectiveness on vehicle-pedestrian interaction nor the superiority of stop sign installation over other interventions like educational efforts and geometric design consideration.

Marshall (2008) and Biswas (2017) studied the effects of on-street parking on pedestrian safety. They came to a similar conclusion that, unlike the previous conviction of transportation engineers, on-street parking improves the safety of pedestrians and reduces the risk of road injury. They argued that on-street parking in urban areas is responsible for reducing the speed of vehicular traffic while simultaneously creating a buffer between pedestrians and motorways. They also mentioned other socioeconomic benefits of on-street parking, making it a viable option compared to off-street surface lots and garage parking.

It has been proven that people with sensory or mobility impairment are at a greater risk of accident (Ashmead, D. H. et al., 2005); therefore, measures like tactile paving that increases their accessibility are vital to providing street safety for all (Asadi-Shekari, Z. et al., 2015). However, Ormerod M. et al. (2015) criticized the possibility of tactile paving hindering the walking experience of senior pedestrians or people with mobility impairments; therefore, they suggest a review of the guidance on tactile paving with emphasis on its detectability and tonal contrast.

Table 1. Previous Research on Influential Environmental factors Regarding Pedestrian safety

References	**Environmental factors**		**Selected factors in the context of Sang-e-Siah**
Stoker, P., et al(2015)	Density Regional Development Urban Sprawl		- Street Treatment (Reducing vehicle speeds)
	Street Treatment(Reducing vehicle speeds)	- Speed Humper - Raised Crosswalk	
Zhu, M., Sze, N. N., & Newnam, S.(2022)	Street trees		- Street trees
Biswas, S., Chandra, S., &	Limited visibility	- On-street parking	- On-street parking

Ghosh, I.(2017) Marshall, W. E., Garrick, N. W., & Hansen, G.(2008)			
Budzynski, M., et al(2019)	Insufficient facilities for disabled persons	- Insufficient facilities for the visually impaired - Insufficient ramps on the edge of the crossing	- Insufficient ramps on the edge of the crossing Pavement
	Limited visibility	- Parked cars - Fences - Posts - Billboards - Transports stops	
	Pedestrian crossing	- Too long - Crossing cutting across - Width of traffic islands - High speed of vehicles - Lack of drains	
	Other factors	- Pavement - Technical condition	
Osama, A., & Sayed, T.(2017)	Land use	- Residential areas - Commercial - Recreational - Industrial - Retail - Parks - Mixed land use	- Residential areas - Commercial - Recreational - Intersections - Speed limits
	Road facilities	- Intersections - Speed limits - Length of major/minor arterials - Road density	
Zhang H, Li, Y, (2021)	Intersection and roadway design	- Roundabouts - Rumble strips - Lighting conditions - Speed humps - Roadside objects - Pavement condition - Sidewalk width - Crossing indicator - On-street parking - Intersection type	- Lighting conditions - Pavement condition - Sidewalk width - On-street parking - Presence of school - Intersection type

	Land use	- Presence of school - Mixed land use - Department stores - Supermarket	
	Transportation	- Bus stop	
Asadi-Shekari , Z., Moeinaddini , M., & Shah, M. Z.(2015)	Road Condition and Design	- Buffers and barriers - Number of Lanes - Traffic calming features - Buffer and Barriers - Adequate pedestrian crossing facilities - Pedestrian refuges - Planting strips - Marking (crosswalk) - Corner island - Signing - Bollard - Advance stop bar - Curb ramp - Slope	- Lanes - Traffic calming features - Pedestrian refuges - Marking(crosswalk) - Bollard - Advance stop bar - Tactile paving surfaces - Ramp - Curb extension

Primary Material and Results. Sange-Siah Street is a historic path located in the Sange-Siah neighborhood in the historic city center of Shiraz. Connecting "The Shahcheragh complex" and "Vakil complex" to "Darveze Kazerun" gives it immense importance in terms of urban mobility, and on top of that, the concentration of boutique hotels and historical tourist attractions makes the case to study pedestrian safety factors and their effects on it as a typical organic street in Iran.

Due to the high variability of factors impacting pedestrian safety, this study is focused on environmental factors and their effects on pedestrian safety. These factors are evaluated in 3 sections in the Sang-e-Siah. The first (A) starts from "9th of Dey" street and ends before Moshir mosque. The Second part of the street starts from there and continues after "Sibawayh Park" and The last part is the distance between "Sibawayh Park" to the "Seyyed Taj o Din Gharib's Shrine." The built environment correlates with safety such as land use categories, On-street parking, Public transportation, Reducing vehicle speed, environmental gadgets, Population and trees density, Destination accessibility, Lighting condition, Road width, and sidewalk has investigated in the context of three different parts of Sange-siah describing by qualitative method describing each factor in 3 levels of High, Medium, and Low.

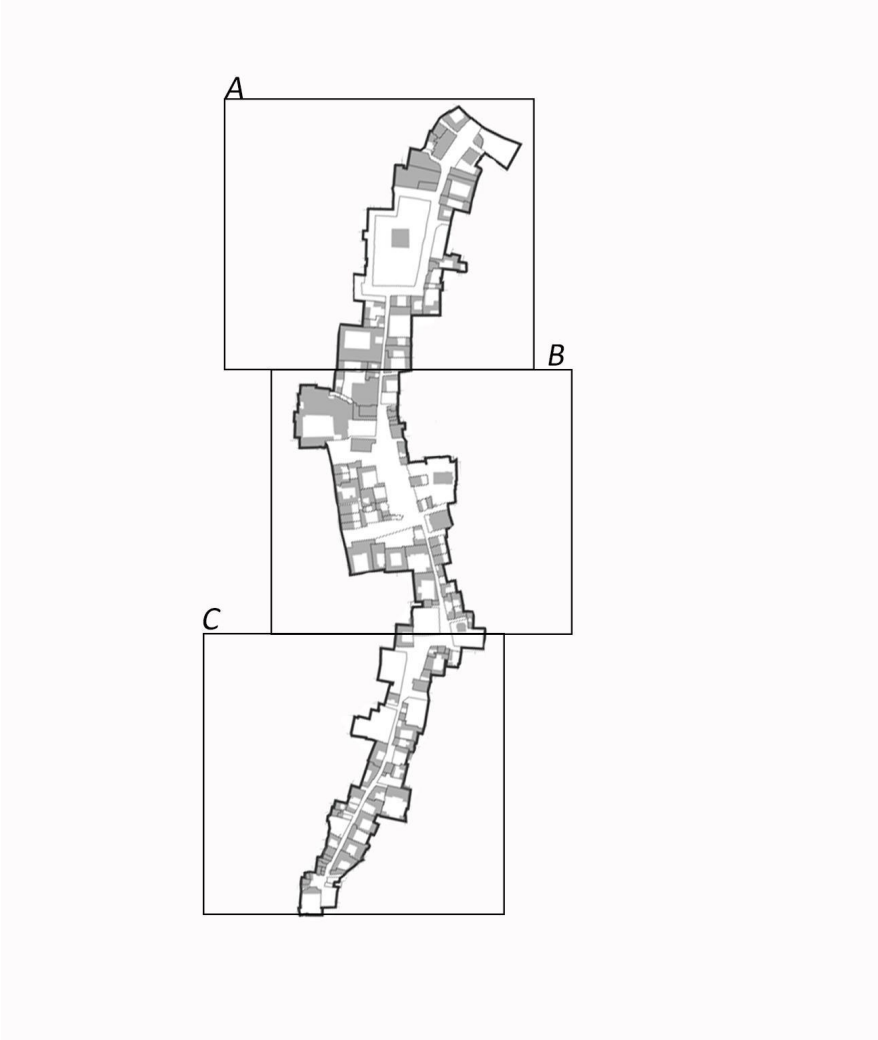

Figure 1. Sange-siah path- Shiraz- Iran

Table 2. Environmental factors Influencing Pedestrian safety

Environmental Factors		Efficacy on pedestrian safety	A	B	C	Reference
Land use	School area	Negative	Med	Low	Low	(Heydari, S., Miranda-Moreno, L., & Hickford, A. J., 2020)
	Commercial	Negative	Low	Low	Low	(Osama, A., & Sayed, T., 2017)
	Residential	Positive	Med	High	High	(Osama, A., & Sayed, T., 2017)
	Recreational	Positive	Med	High	Low	(Osama, A., & Sayed, T., 2017), (Zhu, M., 2022)
Buffers and Barriers	On-street parking	Positive	High	Med	Med	(Marshall, W. E., Garrick, N. W., & Hansen, G., 2008), (Biswas, S., Chandra, S., & Ghosh, I., 2017)

	Street trees		Med	Low	Med	(Asadi-Shekari, 2015), (Kim. D., 2019), (Zhu, M., Sze, N. N., & Newnam, S., 2022)
	Bollard		High	High	Low	(Asadi-Shekari, 2015), (Zhu, M., Sze, N. N., & Newnam, S., 2022)
Sidewalk Condition	Sidewalk presence	Positive	High	High	Low	(Asadi-Shekari, 2015)
	Warning signs	Positive	Low	Low	Low	(Asadi-Shekari, 2015)
	driveway	Negative	Low	Low	Low	(Asadi-Shekari, 2015)
	Ramp	Positive	Low	Low	Low	(Asadi-Shekari, 2015)
	curb extension	Positive	Low	Low	Low	(Asadi-Shekari, 2015)
Road Condition	Textured pavement	Positive	Med	Low	Low	(Asadi-Shekari, 2015)
	Road width	Positive	Med	Low	Low	(Stoker, P., et al, 2015), (Barón L, et al. 2021)
	Intersection	Negative	Low	Low	Low	(Asadi-Shekari, 2015), (Zhu, M., Sze, N. N., & Newnam, S., 2022)
	Lighting	Positive	Med	Low	Low	(Asadi-Shekari, 2015), (Budzynski, M., et al, 2019), (Barón L, et al, 2021)
	Speed hump	Positive	Low	Low	Med	(Stoker, P., et al, 2015), (Obeid, H., et al, 2017)
	Marked Crossing	Positive	Low	Low	Low	(Stoker, P., et al, 2015), (Asadi-Shekari, 2015), (Obeid, H., et al, 2017), (Zhu, M., Sze, N. N., & Newnam, S., 2022)
	Number of Lines	Negative	Low	Low	Low	(Stoker, P., et al, 2015)
	Traffic Signals	Negative	Low	Low	Low	(Asadi-Shekari, 2015), (Osama, A., & Sayed, T., 2017), (Zhu, M., Sze, N. N., & Newnam, S., 2022)
	Pedestrian refuge and median	Positive	Low	Low	Low	(Asadi-Shekari, 2015)
	Advance Stop bar	Positive	Low	Med	Low	(Asadi-Shekari, 2015)
	Speed limits	Positive	Low	Low	Low	(Stoker, P., et al, 2015), (Asadi-Shekari, 2015), (Zhu, M., Sze, N. N., & Newnam, S., 2022)

Accessibility	Tactile pavement (guiding)	Positive	Low	Low	Low	(Asadi-Shekari, 2015)
	Tactile pavement (warning)	Positive	Low	Low	Low	(Asadi-Shekari, 2015)

There are several environmental features with the primary objective of reducing vehicular speed, and through that, they reduce pedestrian exposure to accidents. Among them, most environmental features in Sang-e-Siah consist of road width, texture pavement, street trees, and on-street parking. Ironically, these features ensure the safety of pedestrians by making drivers feel unsafe to speed up. In the first section of the street (A), unauthorized on-street parking keeps the pace of vehicles down. However, the street width between "Bibi Dokhtaran Shrine" and "Moshir mosque" is so narrow that it only allows the passage of one car at a time.

Several environmental features protect pedestrians by separating them from motorways and as a buffer between sidewalks and vehicular traffic, ensuring the pedestrian's right of way alongside the street. Buffers and Barriers such as bollards, street trees, and on-street parking are examples that are effective for increasing pedestrian safety. Results of several studies suggest that these barriers make the streets a safer place for pedestrians by decreasing vehicle speeds and reducing the risk of accidents. Street trees and on-street parking are specifically used to separate the street from the open space in front of "Moshir mosque" and "Sibawayh Park," and bollards are to narrow the vehicular line, even on widened parts of the street that lack quality; these environmental features are important as well.

Land use is another influential factor that strengthens or hinders pedestrian safety in Sang-e-Siah. Since parks and recreational land uses are proven to have a positive impact on improving pedestrian safety, their presence has been studied in Sang-e-Siah too. The middle part of street (B), by having two recreational lands used for"Sibawayh Park" and the plaza in front of "Moshir mosque," ranks as high on the spectrum. At the same time, (A) is considered medium, having only "Bibi Dokhtaran shrine," and (C) is low due to the lack of these land uses. Nevertheless, the off-street surface lots and schools can put pedestrian safety at harm. Fortunately, the nearest school to Sang-e-Siah Street is Ilkhani School which only affects section (A) of the street, and due to the lack of off-street parking land use, unauthorized parking is standard in Sang-e-Siah.

Another important aspect of pedestrian safety on Sang-e-Siah Street is the sidewalks. The sidewalk facilities and Their presence on the site have been measured by considering their condition and whether or not there is a sidewalk on both sides of the street. Regarding pedestrians' presence in more sections (A) and (B), C is low. Sidewalk facilities like curb extensions and ramps can provide a safer walk, but these facilities are lacking in all three sections of Sange-Siah.

Road condition is vital to pedestrian safety evaluation in Sang-e-Siah, consisting of many environmental factors (11). However, many of them, such as; signals and marked crosswalks and signings, are absent in Sang-e-Siah Street. The main road condition of Sang-e-Siah is its narrowness, consistent with notions of "road diet" and "woonerf." Due to the organic nature of Sang-e-Siah Street, its width is extremely narrow in all three parts of the street. This narrowness has proven to be a positive aspect of the environment and positively correlates to pedestrian safety (Stoker P. et al., 2015, p. 383).

Conclusion. This study aimed to conduct an analytical study on environmental factors that supposedly influence pedestrian safety. As shown in (table 2), the results of evaluating Sange-Siah Street in three separate sections (A, B & C) was that section (A) is the safest part of the street, having most factors ranking in the high or middle tire. Meanwhile, section (C) exposes pedestrians to the most risk with the lowest provision of pedestrian safety, and section (B) is in the middle. The width of the street, textured paving, bollards, and on-street parking were the most dominant environmental features that improved the safety status of pedestrians.

In contrast, some features, like stop bars and tree rows, had less impact due to their poor application. On the other hand, the lack of some environmental features such as speed hump, marked crossing, and signals are intransitive to reduce the speed of vehicles; therefore, the lack of them is noticeable. The present analytic study gave us a prospect into the most influential factors in the fabric of historical Shiraz regarding pedestrian safety; therefore can be used for further exploration.

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ПІДВИЩЕННЯ БЕЗПЕКИ ПІШОХОДІВ ЗА ДОПОМОГОЮ ЕКОЛОГІЧНОГО АНАЛІЗУ: ПРИКЛАД ВУЛИЦІ САНГ-І-СІАХ У ШИРАЗІ

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Анотація. Сприяння пішохідній доступності в містах стало важливою метою для міських дизайнерів у всьому світі через її позитивний вплив на здоров'я населення, місцевий бізнес та навколишнє середовище. Однак безпека пішоходів залишається значною проблемою, особливо в центральних частинах міст. Це дослідження оцінює вплив факторів навколишнього середовища на безпеку пішоходів на конкретному прикладі вулиці Санг-і-Сіах у Ширазі. У дослідженні застосовано підхід дистанційного аналізу з використанням фотографій з місця подій та карт Google Earth для оцінки міського середовища вздовж вулиці. Вулицю поділено на три ділянки для оцінки та порівняння екологічних факторів на кожному сегменті. Основними показниками, що розглядаються, є землекористування, стан тротуарів і доріг, доступність та інші відповідні елементи, що оцінюються за трирівневою шкалою: високий, середній і низький вплив. Шляхом якісного вивчення факторів навколишнього середовища оцінюється їхній вплив на безпеку пішоходів на кожній ділянці. Дослідження виявляє варіації значущості кожного фактора на різних ділянках вулиці. Деякі елементи мають різний ступінь впливу, тоді як інші демонструють незначний вплив. Завдяки такому якісному порівнянню дослідження має на меті представити комплексні висновки, які дозволять краще оцінити три ділянки на основі спостережень та звітів. Результати дослідження можуть допомогти міським планувальникам і політикам у прийнятті обґрунтованих рішень для підвищення безпеки пішоходів і покращення загальної пішохідної доступності вулиці Санг-і-Сіах та подібних міських коридорів.

Ключові слова: Пішохідна доступність, безпека пішоходів, індикатори безпеки пішоходів, екологічні фактори