ISSN: 2008-5079 / EISSN: 2538-2365
DOI: 10.22034/AAUD.2023.360784.2716

Research Paper

Optimizing the Spatial Design of Urban Metro Stations Using the Space Syntax Method

Masoud Haghlesan[a*]

[a] Assistant Professor, Department of Architecture and Urban Development, Ilkhchi Branch, Islamic Azad University, Ilkhchi, Iran (Corresponding Author).

Received 16 September 2022; Revised 16 July 2023; Accepted 10 August 2023; Available Online 04 December 2023

ABSTRACT

In recent decades, the shortage of urban land in metropolises has prompted urban designers and policy makers to use underground urban environments as emerging urban spaces. The main issue with underground urban spaces, albeit less attended to, is designing and optimizing urban metro stations as places for people's social interactions. Also, failure to pay attention to the spatial structure and quality of urban metro stations has caused a series of problems with using the internal spaces of these stations. The goal of this article was to use the space syntax method to identify, evaluate and optimize stations using the components of wayfinding, orientation and visibility at Tabriz's urban metro stations. In this study, the components of wayfinding, orientation and visibility were examined at two selected stations in the city of Tabriz, namely Sa'at Square and Kohan Square. This study used descriptive and analytical methods and analyzed data using the space syntax method based on graphic and statistical maps, extracted from axial map analysis, convex map (orientation) analysis, isovist (visibility) analysis and agent (natural movement) analysis. These analyses were found to greatly contribute to designing and optimizing spaces. Findings revealed that the space syntax method greatly contributes to the qualitative design of urban metro stations. Compared to the Kohan Square station, the Sa'at Square station is well organized spatially by straight routes and thus features in analyses relatively good performance in terms of visual and physical permeability, integration and spatial structure.

Keywords: Urban Underground Spaces, Metro Station Design, Space Syntax, Metro Space Optimization.

* E_mail: ma.haghlesan@iau.ac.ir

1. INTRODUCTION

Urban metro station spaces are among the most widely used public spaces in cities, which are deeply connected with urban texture and public life. They are also places that influence social, economic, cultural, artistic and service interactions between various groups of people. These spaces also help form special needs and behaviors. The significance and effects of these emerging urban spaces in Iranian cities have recently been considered in architecture and urban development (Transportation Research Board 1999; Durmisevic and Sariyildiz 2001; Peek and Erik 2006; Mardomi and Ghamari 2011). Since the 1980s, the designs of urban metro space stations have been studied, and the effects of spatial configurations and their systemic use in designing and evaluating the quality of underground spaces, as well as their qualitative improvement have been investigated. In the meantime, wayfinding, orientation and visibility are the core indicators of designing and building underground space stations. The special forms of these stations, along with the combination of signs, media, symbols, light, displays, etc., affect spatial readability (Carmody et al. 1994; Lopez 1996; Durmisevic and Sariyildiz 2001; Belanger 2006). This study investigated the city of Tabriz for its special situation and development of urban underground transportation spaces. The formation of urban metro stations and their spatial configuration designs can help promote their spatial quality. This study investigated two metro stations, situated in Municipality District 1 of Tabriz, where the space syntax method has been used to improve the wayfinding, orientation and visibility of the spaces. For this, the following question are raised:

- How can space syntax be effectively used to evaluate wayfinding, orientation and visibility in urban spaces?
- Which measures can be taken to optimize the two metro stations of Tabriz in terms of wayfinding, orientation and visibility?
- What are the special solutions to investigate and improve the wayfinding, orientation and visibility of the two stations and other stations?

2. RESEARCH LITERATURE

In recent decades, numerous researchers have studied the structural, managerial, social, passive defense, urban space, architectural and environmental aspects of urban train transportation spaces. Structurally, the studies have examined the surface settlement of the stations, underground structural performance, etc. (Bobylev 2010; Rezaei Farei and Ehterami 2019); managerially, they have investigated the effects of the environments surrounding the stations on diverse and continuous activities (Rafiyan and Asgari 2009); socially, they have investigated the satisfaction of neighborhood residents based on social, physical and perceptual quality indicators (Abbaszadegan et al. 2010; Hernandez, Monzon, and Ona 2015; Hee Lee et al. 2016; Saygaonkar, Swami, and Parida 2016; Puoravari 2020); architecturally, they have investigated the physical and mental effects of internal designs (Aghajani and Shahhosseini 2020), and environmentally, they have investigated the environmental impacts on establishing visual communications between the user and the improved environmental quality in urban spaces (Durmisevic and Sariyildiz 2001; Samanifar, Khazaei, and Verij Kazemi 2019). Also, from a passive defense perspective, the studies investigated the location of the stations in terms of accessibility to rescue centers, and provided design models for the metro security (Danainia and Majidi 2019; Salmani, Valizadeh, and Feizizadeh 2018; Carmody, Hute, and Sterling 1994). Meantime, from an urban space perspective, the studies also examined urban spaces in terms of accessibility to other urban spaces and their performance in urban landscapes (Kim 2007; Belanger 2006; Broere 2015; Bagher Khosroshahi 2015; Falahati 2015).

Concerning the application of the space syntax method in analyzing metro underground spaces, some research has been conducted in urban space and architecture domains, as summarily listed by Table 1. Unfortunately, these studies have not comprehensively examined Iran's urban underground transportation spaces and the use of space syntax in urban spaces, as well as architectural and environmental features. Hence, the present study aimed to investigate and analyze the wayfinding, orientation and visibility indicators of the two metro stations in Tabriz City, namely Sa'at and Kohan Squares using the space syntax method.

Table 1. Research on Using Space Syntax in Metro

Domains	Research on Using Space Syntax in Metro	Researchers
Urban Spaces	Conducting field surveys and counting pedestrians, investigating variable factors affecting spatial vibrancy for the fast development of underground spaces in metro regions	Xu, Bai, and Chu (2016)

Domains	Research on Using Space Syntax in Metro	Researchers
Urban Spaces	Presenting a major complementary criterion for geographical accessibility and providing a general insight into urban accessibility models for the initial stages of planning	Morales et al. (2016)
	Analyzing the physical integration of cities in terms of urban transportation systems	Zheng, Du, and Wang (2021)
Architecture	Investigating and comparing two systems for designing metro stations based on space syntax and using spatial syntax model for emphasizing spatial quality differences	Edgü (2007)

3. METHODOLOGY

This study used the space syntax method to evaluate two metro stations (No. 11: Sa'at Square) and (No. 12: Kohan Square). Here, the study used the descriptive-analytical strategy-based quantitative method. Data were collected by library and field survey methods, as well as via studying documents and available maps and also by observation, sketching and simulating case studies. The method consists of four stages: 1) Mapping urban underground spaces; 2) conducting visibility, axial, isovist and agent-based analyses; 3) evaluating results and 4) comparing the plans of the studied stations. Data were analyzed by Depth Map software and simulating station spaces. Figure 1 illustrates space syntax findings, which are used for evaluating and improving urban underground spaces.

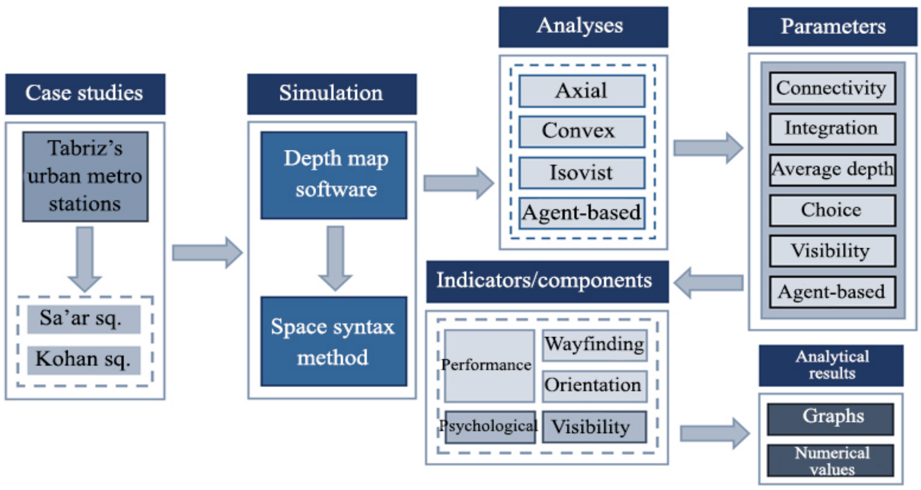


Fig. 1. Conceptual Model of the Study

4. THEORETICAL FOUNDATIONS

Theoretical basics in this study concern the subject and serve as the basis for study findings as well as analyzing data obtained from case studies. Theoretical foundations are based on two items of space syntax and urban transportation systems.

4.1. Space Syntax

Space syntax refers to a method by which spaces in architectural projects are analyzed based on detailed plans and proposed design models (Hillier and Hanso 1984; Hillier 1996). Space syntax is concerned with analyzing spatial arrangement and combining various models based on graphic models and templates to improve the scientific and mathematical interpretations of spaces and the interrelationship between environmental fabric and human behaviors (Hillier and Hanso 1984, 294; Barani et al. 2012; Mustafa and Hassan 2013, 445).

In order to analyze spatial structure, the space syntax method, along with a number of parameters, provide the following spatial characteristics:

Connectivity: It refers to the degree to which a number of lines meet a node. The node with a higher connectivity relates with more nodes and has better spatial communications (Oftadeh 2016). Connectivity refers to the connection of spaces together for understanding collective spaces and facilitating flows between spaces (Young et al. 2015, 2-16).

Integration: It refers to the extent to which a point relates to the whole structure in a set or its subsets. If fewer spaces are covered to reach a space, that space will have greater level of integration, and vice versa (Jiangl, Claramuntz, and Klarqvist 2000). Integration is linearly and directly related to connectivity; the greater the connectivity of a space and the greater it is connected with more nodes, the greater the level of integration (Heydar, Ghasemian-Asl, and Kiaei 2017).

Depth: This indicator is divided into two parts: 1) the metric depth or the same distance between two nodes and 2) the number of nodes to be covered for going from Node 1 to Node 2 (Memarian 2002).

Choice: It refers to the probability of choosing routes and peoples' presence in spaces. This map shows the routes most probably used to get to the destination (Khodabandelo, Soltanifard, and Zanganeh 2018).

"Space syntax" theory uses urban space models and graphs to demonstrate urban space configurations. The models obtained by urban space syntax and configuration help identify urban structures and human behaviors (Jiangl, Claramuntz, and Klarqvist 2001).

Spatial configuration (spatial structure) can be considered the starting point of building plan analysis using space syntax; however, the main source of analyses is a network of graphs representing the abstract images of spatial (structure) configuration (Bafna 2003). In order to analyze spatial structure using the space syntax method in Depth Map software, data can be obtained in the form of graphs, tables and diagrams. In the following, some of the applicable concepts of these data (Fig. 2) are briefly explained:

Axial map analysis: An axial line indicates the longest visibility line in an urban space or building. This term demonstrates the manner of humans' movement in lines on streets and roads or in rooms and corridors.

Convex map analysis: Here, the analysis uses convex maps for analyzing buildings and public spaces between buildings. A convex space is defined as follows: "All points inside a space that can be connected to all other points without passing through the space border".

Isovist analysis: An isovist field is indicative of a panoptic view an individual has from a given point in an urban space. This term is used for orienting or wayfinding in an urban texture (Hillier 1988).

Agent-based analysis: It refers to how people position their direction in urban areas and inside buildings. Experimental tests on peoples' movement in virtual environments with strange angles revealed a significant correlation between humans' real behaviors and the results of all-line analyses and point depth analyses (Conroy Dalton 2001).

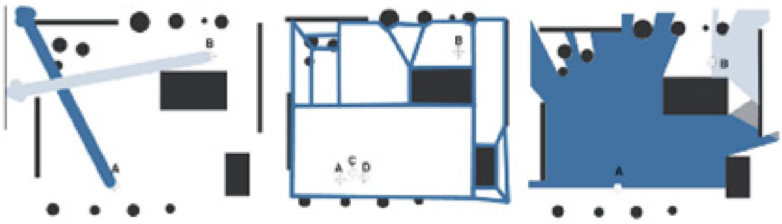


Fig. 2. (From left) Axial Lines, Convex and Isovist Spaces

(Van Nes 2012)

The main hypothesis of spatial analyses states: Man moves in lines, interacts in convex spaces, and experiences a variable panoptic view when moving in a constructed environment. Hence, this can be useful for testing urban underground space requirements. This study aimed to evaluate the spatial configurations of two urban metro stations in Tabriz, Iran, and to find solutions to optimize urban underground space designs in prospective studies.

4.2. Urban Transportation System

A metro system serves as an instrument for the express railway transportation across the city; it is an infrastructure whose all or some parts are constructed under the ground and move commuters in certain destinations through fixed stations available on the ground level. The metro system accounts for the highest and fastest movement of commuters and the lowest rate of interference with the urban transportation systems (Heydari and Zaemi 2017). A metro system consists of two physical elements of lines and stations, with the latter playing a more critical role due to their closer relations with citizens and the collective environment. In addition to transportation aspects, stations are focused in terms of fabric and social impacts, and thus play a public space role (Durmisevic and Sariyildiz 2001). Metro systems also serve as an interface space for being situated in the center of vehicular transportation (Ranger 2009).

The metro stations' spatial quality components help facilitate traffic and design routes, which cover all spaces and give commuters the right to choose the better route (Sampaio, Neto, and Sampaiom 2008). The easiness of accessibility and safety in metro stations are also critical (Tyrinopoulos and Antoniou 2008).

The design and quality of metro station spaces depend on the following:

Functional: The internal communication of spaces, movement efficacy, manners of communication, adjacency, wayfinding (routing), spatial integrity, sound insulation, light and illumination, space temperature.

Psychological: Reflection of users' experience of

the space, security, convenience and comfort, active defense in crises, visibility, light, public presence, wayfinding, attractivity and retention
Structural: Flexibility, color, materials, separating walls, dimensions, furniture (Mehrabian 1976; Durmisevic 1999; Dusmisevic and Sariyildiz 2001; Maria Kido 2010).

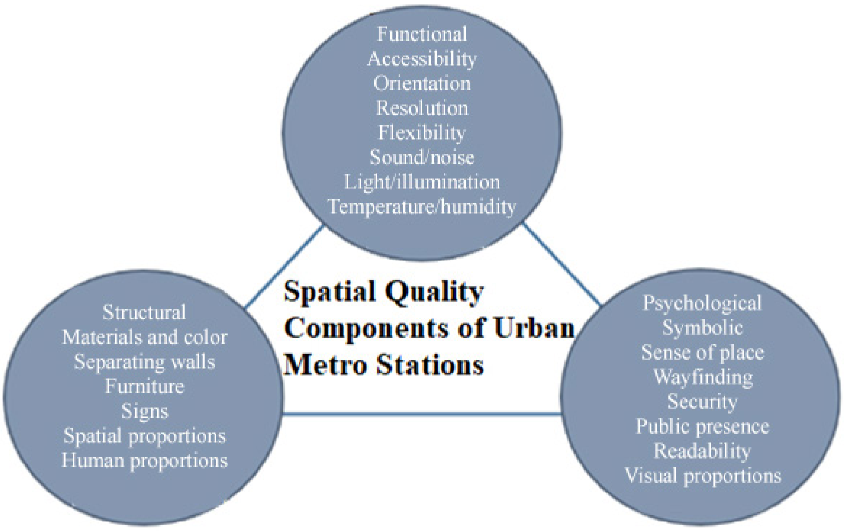


Fig. 3. Theorists' Views of Spatial Quality Components at Metro Stations

A place with strong connectivity and integration refers to a space where pedestrians have easy access to its different areas. Therefore, the pedestrian can choose a route that has more integration. The space syntax method is capable of predicting the pedestrian's flow of movement at an urban metro station based on determined parameters. These parameters can explain the real status of pedestrians at those stations. These parameters show the pedestrian's natural movement within a pathway, which is similar to the place's real status, as more people tend to choose a nearer route. Since pedestrians tend to choose routes of high integration, relevant results analyses could help predict active points inside the stations during a design process. Based on the analysis of the internal spaces of metro stations, the behavior of the pedestrian at the station is suggested to be closely connected with spatial configuration. This enables designers to better navigate the flow of the pedestrian by optimizing space configuration and improve spatial quality and space design indicators.

5. STUDIED CASES

Tabriz's urban railway has five lines, with Lines 1 to 5 extending 17.2, 22.4, 9.8, 15.4 and 5.1 km, respectively. The case studies are in Line 1, which has 18 stations, starting from E'l Goli Square and ending up in Laleh Alley. This study focuses on the central section of Line 1 between Station Nos. 11 and 12. The reasons for selecting these case stations were their similar plans in terms of floors, the same number of users of the stations due to their location in the central part of the city and in Tabriz Bazaar, the location of the two stations in Line 1 of Tabriz's urban metro system as the first metro line, and the location of Station No. 12 (Kohan Square) in the center of Line 1 as the mother line for line changes.

Fig. 4. Location of Sa'at Square Station (No. 11) and Kohan Square Station (No. 12) in Line 1 of Tabriz's Urban Train (Tabriz Metro Organization)

The Sa'at Square station (Station No. 11) of Line 1 is situated on Imam Khomeini St. and in Sa'at Square (Tabriz municipality) and the Kohan Square station (Station No. 12) of Line 1 is situated on North Shariati St. and in Kohan Square (Atiq Square).

Table 2. Characteristics of Sa'at Square Station (No. 11) and Kohan Square Station (No. 12) in Line 1 of Tabriz Urban Railway

Station No.	11	12
Station Name	Sa'at	Kohan sq.
Type of Station	Deep	Deep
Number of Floors	3	3
Number of Entrances	3	3
Built-up Area (m^2)	10680	13177

(Tabriz Metro Organization)

6. DATA ANALYSIS

Ideally, public transportation users in underground stations can easily find their ways out of various entrances into platforms down in the stations and from there to street levels. Designing such "stations" can largely reduce the number of direction changes and angular deviations required along the routes. Public transportation users at the stations can remember their mental experiences of the main routes when traveling the routes from the street levels down to the underground platforms and also the spaces they go through. Therefore, at the studied stations, four space syntax parameters were developed for evaluating the spatial connectivity of the current situation. These parameters include axial analysis, point depth, the visibility of all points and the natural (convex) movement of people. To determine whether an underground urban space can be improved in terms of wayfinding, orientation and visibility, the following stages are recommended:

1. Providing an urban underground space map and distinguishing between publicly accessible areas and inaccessible area
2. Using floor plans for axial, depth, visibility and convex (natural) movement analyses
3. Evaluating analysis results and identifying "strong" and "weak" areas of urban underground spaces
4. Evaluating and comparing the floor design results of both stations

6.1. Axial Analysis

Axial analysis must be performed based on all straight pedestrian lines inside metro stations. These lines are sketched in the form of straight lines in the floor plan prior to the analysis. Analyzing all lines show all access features. The more an axis is integrated, the more it turns red, which shows the lowest direction changes relative to other axes at the station. Conversely, the less the integration, the blueish the axis will become.

6.1.1. Sa'at Square Station

As given by Table 3, the axial analysis of spatial configuration for passenger wayfinding at the Sa'at square station is used for analyzing the four quantitative indicators of connectivity, integration, mean depth and choice.

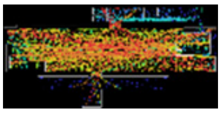
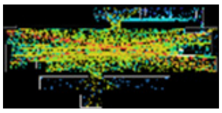
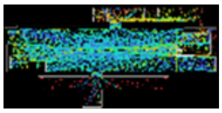
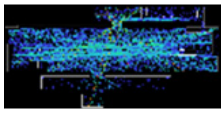
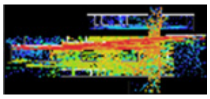
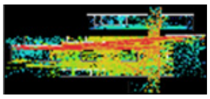
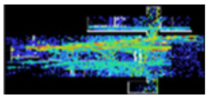
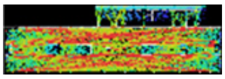
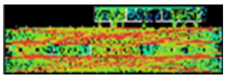
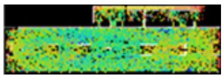
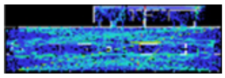
Connectivity: On the ground floor, the parameter of connectivity records a numerical index of 514; on the first underground floor, the ticket-selling center and on the second underground floor, the place where the platforms connect each other hold the highest rates of connectivity with numerical indexes of 1526 and 1586, respectively.

Integration: The ticket-selling center on the ground floor holds the highest spatial integration with a numerical index of 22.4875. On the first underground floor, the ticket-selling saloon and the area where commuters are directed downstairs (platforms) hold the highest spatial integration with a numerical index of 19.5628. On the second underground floor, the center of the platforms and the back of access points and the place of boarding hold the highest spatial integration with a numerical index of 20.1689.

Mean depth: The lowest mean spatial depth on the ground floor pertained to vertical accesses at a numerical index of 1.96975. On the first underground floor, the mean spatial depth pertains to the ticket-selling kiosk with a numerical index of 1.98023. On the second underground floor, the mean spatial depth pertains to the southern platform with a numerical index of 1.97268.

Choice: The parameter of choice in the red axis is seen distributed in the center of the ground floor center, holding the highest degree of choice with a value of 3298. On the first underground floor, the red axis in the northwestern area, which includes the ticket-selling kiosk, the ticket-selling saloon and the commuters' entry gates towards the second floor, holds a value of 13232. On the second underground floor, the red axis in the center of the saloon and the place of boarding (platforms) records a value of 33364. The highest rate of choice in a space or station indicates strong spatial connectivity. Higher spatial connectivity indicates higher spatial integration. Therefore, choice is directly related to connectivity and integration.

Table 3. Axial Analysis using Space Syntax for Commuter Wayfinding at the Sa'at Square Station

	Connectivity	Integration HH2	Mean Depth R2	Choice R2
Ground Floor				
min	6	4.14804	1.31007	0
mean	260	13.31777	1.63991	1.649
max	514	22.4875	1.96975	3298
-1				
min	6	4.33333	1.45324	0
mean	766	11.948065	1.716735	6616
max	1526	19.5628	1.98023	13232
-2				
min	10	4.05759	1.44076	0
mean	798	12.113245	1.70672	16682
max	1586	20.1689	1.97268	33364

6.1.2. Kohan Square Station

As given by Table 4 and Figure 5, the axial analysis of spatial configuration for passenger wayfinding at the Kohan square station is used for analyzing the four quantitative indicators of connectivity, integration, mean depth and choice.

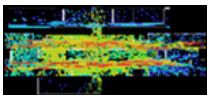
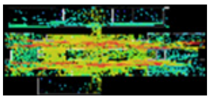
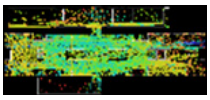
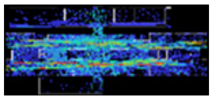
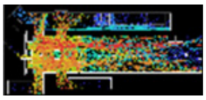
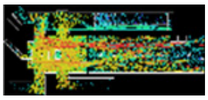
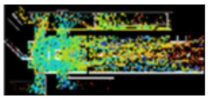
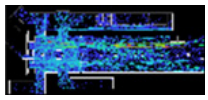
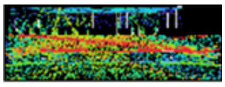
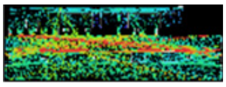
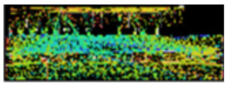
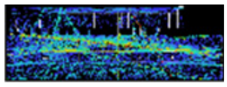
Connectivity: The highest connectivity pertains to the ticket-selling saloon on the ground floor with a numerical index of 1014. On the first underground floor, the ticket-selling saloon and on the second underground floor, the place of platforms hold the highest connectivity with numerical indexes of 931 and 716, respectively.

Integration: Spatial integration in vertical accesses on the ground floor has a numerical index of 18.6457. On the first underground floor, the northern ticket-selling area holds a numerical index of 19.6272, and on the second underground floor, the center of the platforms and the place of boarding hold the highest spatial integration at 20.6444.

Mean depth: The mean spatial depth on the ground floor pertains to the access galleries with a numerical index of 1.98762. On the first underground floor, the mean spatial depth pertains to the access galleries at 1.97209, whereas the lowest mean spatial depth on the second underground floor pertains to the metro station with a numerical index of 1.96393.

Choice: At the Kohan square station, on the ground floor, the highest rate of choice is seen in red axes in two northern and southern areas of the ticket-selling saloons, with the southern part showing a higher value of 14546. On the first underground floor, the red axis in the northern area, which includes access galleries, ticket-selling kiosks, the ticket-selling saloon, and the commuter entry gates towards the second underground floor, holds a numerical index of 13933. On the second underground floor, the red axis in the northwestern area and at the place of boarding (northern platform) holds a value of 6378.

Table 4. Axial Analysis using Space Syntax for Commuter Wayfinding at the Kohan Square Station

	Connectivity	Integration HH2	Mean Depth R2	Choice R2
Ground Floor				
min	3	3.14706	1.43746	0
mean	508.5	10.89638	1.71254	7273
max	1014	18.6457	1.98762	14546
-1				
min	6	3.73764	1.41001	0
mean	468.5	11.68242	1.69105	6966.5
max	931	19.6272	1.97209	13933
-2				
min	6	3.98339	1.37027	0
mean	361	12.313895	3.3342	3189
max	716	20.6444	1.96393	6378

6.2. Analysis of Convex Spaces (Orientation)

Point depth analysis shows the degree of direction changes from any point in the analyzed space to all other points. How many times should one change his direction from a certain position at the station if he wants to traverse all over the station? Point depth analysis divides a space into grid cells and calculates the extent to which each cell connects with all other cells in the grid (Turner 2007). A lower point depth is also considered for optimal orientation. Point depth analysis is used for locating the most and the fewest areas of orientation in underground transportation, and it reveals how the overall plan of the stations and the location of the piers, advertising walls, fences and advertisement may affect the station orientation.

6.2.1. Sa'at Square Station

Connectivity: Based on spatial connectivity analysis, on the ground and -1 floors, the ticket-selling saloons hold numerical indexes of 24 and 41, respectively, and on the second underground floor, the platforms hold a numerical index of 21. Therefore, the highest rate of connectivity pertains to the ticket-selling saloon on the first underground floor.

Integration: Based on convex space analysis, the best orientation with high integration pertains to the ticket-selling saloons with numerical indexes of 6.334 and 20.646, respectively, on the ground and first underground floors'; also, the best orientation with high integration pertains to the platforms with a numerical index of 25.121 on the second underground floor. However, the southern platform holds the highest integration with a numerical index of 18.185.

Mean depth: The mean depth on the ground and the first underground floors pertain to access galleries with numerical indexes of 2.95 and 1.727. The mean depth on the second underground floor pertains to the platforms with a numerical index of 2.33. As a result, the highest commuter route orientation is noted on the ground and second underground floors, while the lowest wayfinding on the first underground floor pertains to the ticket-sale kiosk and the area where commuters depart the station.

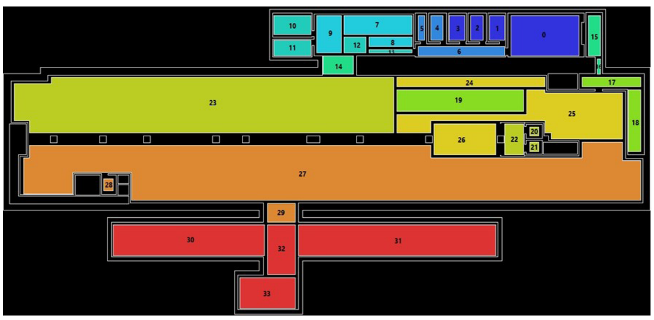


Fig. 5. Convex Space Analyses using Space Syntax Method for Orientation on the Ground Floor at the Sa'at Square Station

Table 5. Convex Space Analyses using Space Syntax Method for Orientation on the Ground Floor at the Sa'at Square Station

Ground Floor	Access Galleries		Ticket-Selling Saloons					Vertical Accesses				
Spaces	32	33	23	24	26	25	27	19	20	21	30	31
Parameters												
Connectivity	5				24					7		
Integration	4.194				6.334					4.924		
Mean Depth	2.95				7.973					8.725		

Fig. 6. Convex Space Analyses using Space Syntax Method for Orientation on the First Underground Floor at the Sa'at Square Station

Table 6. Convex Space Analyses using Space Syntax Method for Orientation on the First Underground Floor at the Sa'at Square Station

First Underground Floor	Access Galleries		Ticket-Selling Saloon							Ticket-Selling Kiosk		Vertical Accesses						
Spaces	34	30	30	31	38	39	40	41	42	26	29	27	28	32	33	35	36	37
Parameters																		
Connectivity	3					41				2					7			
Integration	1.958					20.646				2.75					3.905			
Mean Depth	1.727					12.087				3.776					11.83			

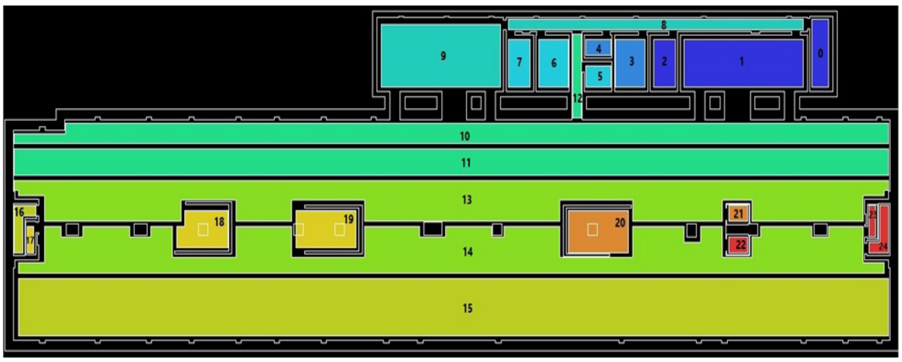


Fig. 7. Convex Space Analyses using Space Syntax Method for Orientation on the Second Underground Floor at the Sa'at Square Station

Table 7. Convex Space Analyses using Space Syntax Method for Orientation on the Second Underground Floor at the Sa'at Square Station

Second underground Floor	Platform		Metro Station		Vertical Access				
Spaces	13	14	11	15	18	19	20	21	22
Parameters									
Connectivity	10	11	3				10		
Integration	6.936	18.185	3.527				9.09		
Mean Depth	1.230	1.083	3.766				9.165		

6.2.2. Kohan Square Station

Connectivity: Based on spatial connectivity analysis, on the ground and first underground floors, the ticket-selling saloons hold numerical indexes of 25 and 23, respectively. On the second underground floor, the platforms hold a numerical index of 38. Therefore, the platforms on the second underground floor enjoy the highest connectivity.

Integration: Based on convex space analyses, the best orientation with high integration is seen in vertical accesses with a numerical index of 11.530 on the ground floor, and in the ticket-selling saloon with a numerical index of 10.296 on the first underground floor. The highest integration rate on the second underground floor pertains to the platforms with a numerical index of 18.933.

Mean depth: On the ground and first underground floors, the mean depth pertains to vertical accesses with numerical indexes of 10.970 and 7.35, respectively. The mean depth on the second underground floor pertains to the platforms with a numerical index of 11.374. As a result, the highest commuter route orientation is noted on the first underground floor and the lowest pertains to the second underground floor.

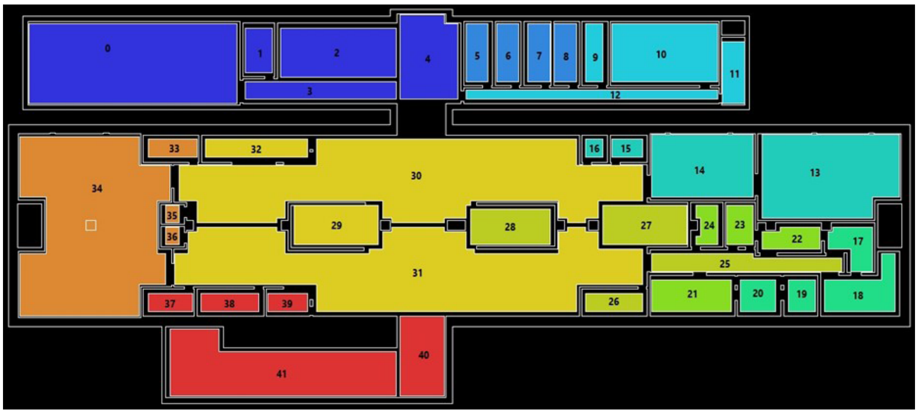


Fig. 8. Convex Space Analyses using Space Syntax Method for Orientation on the Ground Floor at the Kohan Square Station

Table 8. Convex Space Analyses using Space Syntax Method for Orientation on the Ground Floor at the Kohan Square Station

Ground Floor	Access Galleries	Ticket-Selling Saloon		Vertical Accesses		
Spaces	40	30	31	27	28	29
Parameters						
Connectivity	2	25		11		
Integration	1.891	9.632		11.530		
Mean Depth	1.846	2.972		10.970		

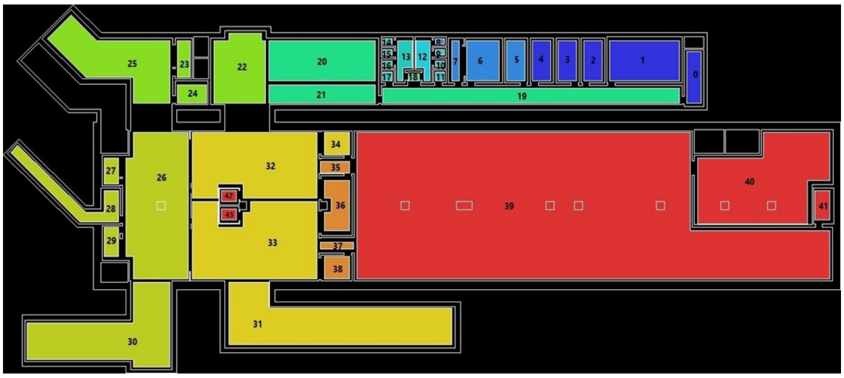


Fig. 9. Convex Space Analyses using Space Syntax Method for Orientation on the First Underground Floor at the Kohan Square Station

Table 9. Convex Space Analyses using Space Syntax Method for Orientation on the First Underground Floor at the Kohan Square Station

First Underground Floor	Access Galleries		Ticket-Selling Saloon			Ticket-Sale Kiosks			Vertical Access			
Spaces	25	30	26	32	33	23	27	29	28	31	42	43
Parameter												
Connectivity	4		23			3			6			
Integration	2.982		10.296			2.798			5.896			
Mean Depth	3.523		4.718			5.38			7.35			

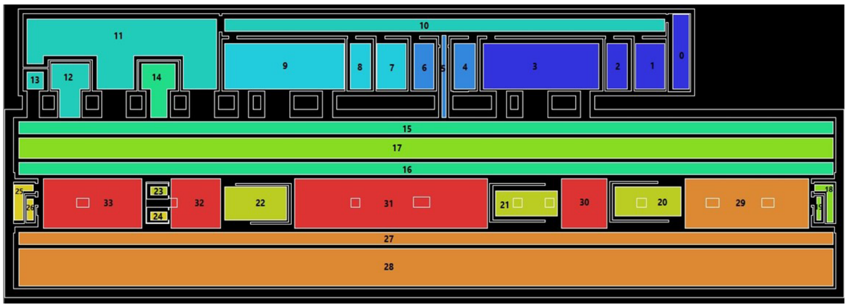


Fig. 10. Convex Space Analyses using Space Syntax Method for Orientation on the Second Underground Floor at the Kohan Square Station

Table 10. Convex Space Analyses using Space Syntax Method for Orientation on the Second Underground Floor at the Kohan Square Station

Second Underground Floor	Vertical Access					Platforms							Metro Stations	
Spaces	20	21	22	23	24	16	27	29	30	31	32	33	17	28
Parameter														
Connectivity	11					38							3	
Integration	7.891					18.933							3.526	
Mean Depth	8.865					11.374							3.77	

6.3. Visibility Analysis (Isovist)

Isovist refers to all visible points from a given point of view in space and based on an environment (Benedikt 1979). Depth Map software is capable of using graphic analyses to calculate the integration of any point or isovist root related to other points in a constructed environment. While axial analysis focused on visible lines in the route the commuter travelled, the isovist goal is to analyze the level of visibility. This denotes how people can see each other and how others can see them (Van Nes and Yamu 2007). The differences between accessibility and visibility determine the differences between depth analysis/point axial analysis and isovist analysis.

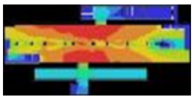
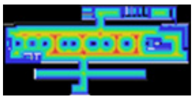
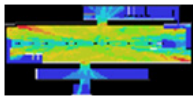
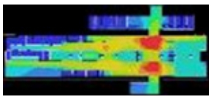
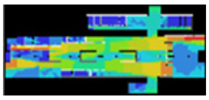
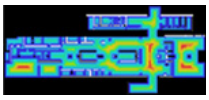
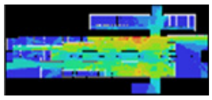
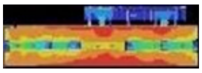
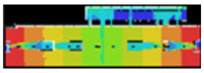
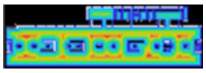
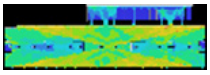
6.3.1. Sa'at Square Station

As given by Table 11, according to visibility analysis, the highest commuter's visibility is noted on the ground floor with a numerical index of 16473800 and the lowest visibility on the first underground floor at 8471870.

The highest maximum radius of visibility is noted on the ground floor with a numerical index of 10400.7 and the lowest maximum radius of visibility on the first underground floor with a numerical index of 9994.12. The highest minimum radius of visibility is noted on the ground floor with a numerical index of 605.428 and the lowest minimum radius of visibility on the first underground floor at 517.443.

The highest occlusivity of visibility that causes the commuter to have his vision blocked and disrupts his orientation pertains to the ground floor with a numerical value of 56818.7, while the lowest pertains to the second underground floor at 37772.6

Table 11. Visible Space Analyses using Space Syntax Method for Commuter's Visibility at Sa'at Square Station

	Isovist Area	Isovist Max Redial	Isovist Min Redial	Isovist Occlusivity
Ground Floor				
min	24454.4	130.535	1.37744	0
mean	8249128	587.6175	303.40272	28410
max	16473800	10400.7	605.428	56818.7
First Underground				
min	33498.4	287.511	0.316912	0
mean	4252685	5141	518	20544
max	8471870	9994.12	517.443	41086.4
Second Underground				
min	38662	208.761	0.0416	100.011
mean	6737881	5260	279	18937
max	13437100	10310	557.676	37772.6

6.3.2. Kohan Square Station

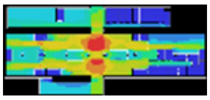
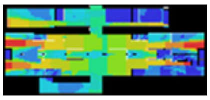
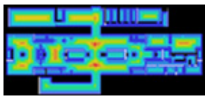
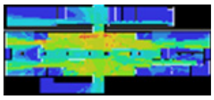
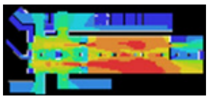
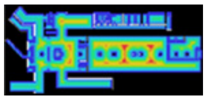
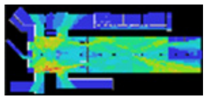
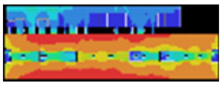
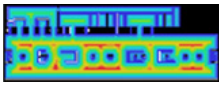
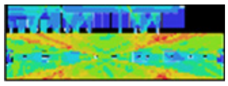
As given by Table 12, according to visibility analysis, the highest commuter's visibility is noted on the first underground floor with a numerical value of 11042000 and the lowest visibility on the ground floor at 9047340.

The highest maximum radius of visibility is noted on the first underground floor with a numerical index of 10340.6 and the lowest maximum radius of visibility on the ground floor with a numerical index of 9980.45.

The highest minimum radius of visibility is noted on the first underground floor with a numerical index of 600.284 and the lowest minimum radius of visibility on the second underground floor at 538.969.

The highest occlusivity of visibility that cause the commuter to have his vision blocked and disrupts his orientation pertains to the first underground floor with a numerical value of 58019.9, while the lowest pertains to the second underground floor at 331337.1.

Table 12. Visible Space Analyses using Space Syntax Method for Commuter's Visibility at Kohan Square Station

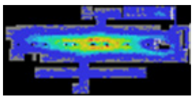
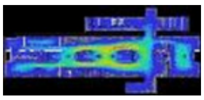
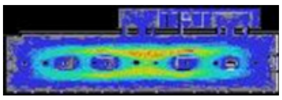
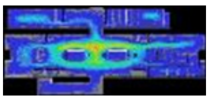
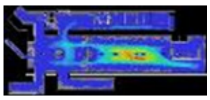
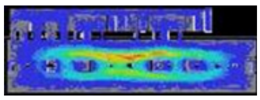
	Isovist Area	Isovist Max Redial	Isovist Min Redial	Isovist Occlusivity
Ground Floor				
min	59800	306.746	0.0942	0
mean	4553570	5144	280	18677
max	9047340	9980.45	558.89	37352.4
First Underground				
min	23399.9	170.548	0.4655	0
mean	5532700	5256	301	29010
max	11042000	10340.6	600.284	58019.9
Second Underground				
min	39440.8	255.962	0.0095	100.002
mean	1378241	5170	270	16619
max	1338800	10082.4	538.969	33137.1

6.4. Agent-based Analyses

Agent analysis results can be useful in estimating the traverse of spaces and urban buildings in future, in addition to traversing the past. A large population of a certain region can be investigated as to how it behaves or how people orientate themselves at a given point in various time intervals.

As shown by Table 13, the natural (agent-based) movement analysis of commuters at the Sa'at square station, which shows the inter-spatial connectivity, reveals that the highest natural movement is noted on the ground floor with an average of 10273, and the lowest natural movement is on the first underground floor with 5304. At the Kohan square station, the highest natural movement is noted on the second underground floor with an average of 8259 and the lowest on the ground floor at 5675.

Table 13. Agent based Space Analyses using Space Syntax Method for Commuter's Natural Movement at Sa'at and Kohan Square Station

Connectivity	Ground Floor	First Underground Floor	Second Underground Floor
Sa'at Square Station			
Min	35	19	23
Mean	5154	2662	4241
Max	10273	5304	8458
Kohan Square Station			
min	41	30	19
mean	2858	3467	4130
max	5675	6903	8259

7. DISCUSSION

The Sa'at square station makes up the degree of integration with great accessibility in a general space. Strong connectivity and higher spatial integrity on the ground floor's ticket-selling saloon and also on the second underground floor's platforms indicate the higher accessibility and strong integration of spaces, as well as their higher integrated and coherent spatial structure. These features enhance the level of permeability and increase the potentiality of movement. Integration and connectivity at this station are higher than those at the Kohan station, which indicates strong wayfinding at the Sa'at station. The southern platform of the second underground floor at the Kohan station suggests lower connectivity and choice, which indicates disrupted wayfinding. Factors such as dispersed and decentralized spaces in the plan, various accessibilities and their arrangement are involved in this. Visibility graphic analyses conclude that the visual permeability of the Sa'at station is higher than that at the Kohan station, which thus increases the commuters' functions. Commuters' natural movement at the Sa'at station is higher than the Kohan station, due to higher visual permeability, integrated spatial structure, space integrity and strong physical connections. Natural movements on the ground floor of the Kohan station, which pertains to the ticket-selling saloon, ticket-selling kiosk, and gates, is highly weak, and it is fully evident on southern platforms, especially at the beginning and end sides.

Table 14. Analytical Summary of Sa'at and Kohan Square Stations

	Egent	Isovist Occlusivity	Isovist Min Redial	Isovist Max Redial	Isovist Area	Choice	Mean Depth	Integration	Connectivity
Sa'at Square	24035	135677.7	1680.547	30704.12	38382770	49.894	5.92266	62.2192	3626
Kohan Square	20837	128509.4	1698.143	30403.45	21428140	34.857	5.092346	58.9173	2661

8. CONCLUSION

According to the research literature, discussed above, most studies have examined urban transportation domains from structural, managerial, architectural, and environmental perspectives, while discussing passive defense and urban space viewpoints. The present study, however, used the space syntax method to investigate the pedestrian's movement from the place of entry to the station and to the place where they board the trains. The study also analyzed pedestrian paths, route orientation, users' traverse of the routes and their visibility by the time of traversing the routes. This type of analysis, which concerns urban metro stations, is, however, lacking in the literature.

Space syntax is effectively used for exploring wayfinding, orientation and visibility in urban spaces. The convenience provided for commuters at underground stations to find their ways and navigate themselves may differ in the Sa'at and Kohan stations. Urban spaces can be evaluated by using the parameters available in space syntax, which include connectivity, integration, depth and choice. Factors such as spatial integrity, spatial continuity, and spatial integration help optimize metro stations across cities (Sa'at and Kohan squares). Physical and spatial factors such as decentralized and dispersed spaces in the plans, a variety of accesses and spatial arrangement have effective roles in the permeability and functions of space, which cause wayfinding, orientation and visibility to be disrupted. The integration, continuity, and spatial connectivity can be established on urban metro stations by creating spatial hierarchy across the way a commuter travels from the source to the boarding area and vice versa.

Using space syntax, inaccessible spaces with weak connectivity can be discovered and strengthened; these spaces have unfortunately been less focused at urban metro stations, as their quantitative features have received greater attention. This method can also be used for land uses as housing, commercial centers, urban spaces, etc. The factors of movement, wayfinding, accessibility, etc. at urban metro stations, which are emerging spaces in underground urban spaces, have received less attention. This study can help designers and policy makers to improve user movement in urban underground spaces, and provide them with the easiness and convenience of wayfinding and orientation, with the fewest urban signs.

ACKNOWLEDGMENTS

This article wasn't supported by any financial or spiritual sponsors.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

MORAL APPROVAL

The authors commit to observe all the ethical principles of the publication of the scientific work based on the ethical principles of COPE. In case of any violation of the ethical principles, even after the publication of the article, they give the journal the right to delete the article and follow up on the matter.

PARTICIPATION PERCENTAGE

The authors state that they have directly participated in the stages of conducting research and writing the article.

REFERENCES

- Abbaszadegan, Mostafa, Razieh Rezazadeh, Maryam Mohammadi, and Sajjad Alipour Ashkili. 2010. Measuring the influencing factors on the level of satisfaction with living in the immediate neighborhoods of Tehran metro stations. *Transport* 7(3): 245-260. http://ensani.ir/fa/article/300850. [in Persian]
- Aghajani, Shekoufeh, and Habib Shahhosseini. 2020. The relationship between the visual preferences of metro station passengers and the interior design of their space, case study: Tabriz metro stations. *Armanshahr* 13(33): 15-26. https://www.armanshahrjournal.com/article_127654.html?lang=en. [in Persian]
- Bafna, Sonit. 2003. Space Syntax A Brief Introduction to Its Logic and Analytical Techniques. *Environment and Behaviour* 35(1): 17-29. http://dx.doi.org/10.1177/ 0013916502238863. Sage Publications.
- Bagherzadeh Khosroshahi, Mahdieh. 2015. Bottom-up urban design (conceptual) formulation of the agenda of the participatory urban design process with the SHART approach (case example: the construction plan of the central metro station in Saat Square, Tabriz). *Soffeh* 25(1): 61-84. [in Persian]
- Barani, Pesian, Mohammad Khosrozadeh, and Abbas Mollazadeh. 2012. The use of space arrangement in Waliasr Street in the city. *Urban Management* 10(29): 81-90. [in Persian]
- Bélanger, Pierre. 2006. Underground landscape: the urbanism and infrastructure of Toronto's downtown pedestrian network. *Tunnelling and Underground Space Technology* 22(3): 272-292. http://dx.doi.org/10.1016/j.tust.2006.07.005
- Benedikt, M. L. 1979. To take hold of space: isovists and isovist fields. *Environment and Planning B: Planning and Design* 6: 47-65. http://dx.doi.org/10.1068/ b060047.
- Bobylev, Nikolai. 2010. Underground space in the Alexanderplatz area, Berlin: research into the quantification of urban underground space use. *Tunnelling and Underground Space Technology* 25(5): 495-50. http://dx.doi.org/10.1016/j.tust.2010.02.013
- Broere, Wout. 2015. *Urban underground space: Solving the problems of today's cities*. Tunnelling and Underground Space Technology. http://journal homepage: www.elsevier.com/locate/tust
- Carmody, John, Olivier Huet, and Raymond Sterling. 1994. Life safety in large underground buildings: principles and examples. *Tunnelling and Underground Space Technology* 9(1): 19-29. http://dx.doi.org/10.1016/0886-7798(94)90005-1.
- Conroy Dalton, Ruth. 2001. "The secret is to follow your nose." In *Proceedings Space Syntax* edited by Peponis, J., Wineman, J., Bafna, S. 3rd International Space Syntax Symposium, Atlanta. http://discovery.ucl.ac.uk/1023/.
- Danainia, Ahmad, and Morteza Majidi. 2019. Evaluation of metro station entrance design indicators in the historical context of Tehran based on passive defense considerations. *Urban studies* 9(33): 39-50. https://urbstudies.uok.ac.ir/article_61316.html?lang=en. [in Persian]
- Durmisevic, Sonja. 1999. The Future of the underground space. *Elsevier Science Ltd* 16(4): 245-233. https://doi.org/10.1016/S0264-2751(99)00022-0
- Durmisevic, Sanja, and Sevil Sariyildiz. 2001. A systematic quality assessment of underground spaces – public transport stations. *Cities* 18(1): 13-23. http://dx.doi.org/10.1016/S0264-2751(00)00050-0.
- Edgü, Erincik. 2007. "Comparative Space Syntax Analysis of Design Strategies for Istanbul Underground Railway System." *Proceedings, 6th International Space Syntax Symposium, İstanbul*.
- Falahati, Leila. 2105. Spatial structure of the city and the sense of security among women (case study: Tajrish metro entrance and South Tehran terminal). *Studies of the Iranian Islamic city* 5(20): 61-73.
- Hee Lee, Eun, George I. Christopoulos, Ming Lu, Min Quan Heo, and Chee-Kiong Soh. 2016). Social aspects of working in underground spaces. *Tunnelling and Underground Space Technology* 55: 135-145. https://doi.org/10.1016/j.tust.2015.12.012
- Hernandez, Sara, Andres Monzon, and Rocío de Oña. 2015. Urban transport interchanges: A methodology for evaloating perceived quality. *Transportation Research Part A: Policy and Practice* 1: 1-13. https://doi.org/10.1016/j.tra.2015.08.008
- Heydari, Ali Akbar, and Nasrin Zaemi. 2017. Prioritization of influential indicators in the sociability of metro stations. *Haft Hasar* 6(19): 7-63. https://hafthesar.iauh.ac.ir/article-1-405-fa.html. [in Persian]
- Heydari, Ali Akbar, Isa GhasemianAsl, and Maryam Kiaei. 2017. Analysis of the spatial structure of traditional Iranian houses using the space syntax method, a case study: comparing the houses of Yazd, Kashan and Isfahan. *Studies of the Islamic Iranian city* 7(28): 21-33. https://www.sid.ir/paper/505298/fa. [in Persian]
- Hillier, Bill, and Julienne Hanson. 1984. *The Social Logic of Space*. Cambridge: Cambridge University Press.
- Hillier, Bill. 1988. Againt enclosure. In *Rehumanising Housing*, edited by Teymus, N., Markus, T., Woaley, T., 63-85. London: Butterworths.
- Hillier, Bill. 1996. *Space is the Machine. A Configurational Theory of Architecture*. Cambridge: Cambridge Uni-

versity Press.

- Jiang, Bin, Christophe Claramunt, and Björn Klarqvist. 2000. Integration of space syntax into GIS for modelling urban spaces. *JAG* 2(3-4): 161-171. https://doi.org/10.1016/S0303-2434(00)85010-2
- Khodabandelo, Hassan, Hadi Soltanifard, and Yaqoub Zanganeh. 2018. Feasibility of the walkability of the network of urban roads in the central part of Qom using Vicor model and space layout theory. *Urban Planning Geography* 6(2): 427-449. https://jurbangeo.ut.ac.ir/article_69179.html?lang=en . [in Persian]
- Kim, Jaecheol. 2007. Testing the Street Connectivity of New Urbanism Projects and their Surroundings in Metro Atlanta Region. *Proceedings, 6th International Space Syntax Symposium, İstanbul*.
- López, Manuel. 1996. Crime prevention within Metro Systems. *European Journal on Criminal Policy and Research* 4(4): 113-119. http://www.dx.doi.org/10.1007/BF02736717.
- Mardomi, Karim, and Hesaam Ghamari. 2011. Influential Architectural Requirements in the Socialization of Subway Station Space. *City Management* 9(27): 31-40. https://www.sid.ir/fa/journal/ViewPaper.aspx?id=150423. [in Persian]
- Maria Kido, Ewa. 2010. Railway Landscape Design and Relationship with Form, Function and Aesthetic. *Japan Railway & Transport Review* 45: 22-30.
- Mehrabian, Albert. 1976. *Public Places and Private Spaces*. New York: Basic Books.
- Memarian, Qolamhossein. 2002. Architectural space syntax. *Soffeh* 12(35): 74-84. https://soffeh.sbu.ac.ir/article_99829.html. [in Persian]
- Morales, Jose, Johannes Flacke, Javier Morales, and Jaap Zevenbergen. 2019. Mapping Urban Accessibility in Data Scarce Contexts Using Space Syntax and Location-Based Methods. *Appl, Spatial Analysis* 12: 205-228. DOI: 10.1007/s12061-017-9239-1.
- Mustafa, Faris Ali, and Ahmad Sanusi Hassan. 2013. Mosque Layout Design: an Analytical Study of Mosque Layouts in the Early Ottoman Period. *Frontiers of Architectural Research* 2(4): 445-456. https://doi.org/10.1016/j.foar.2013.08.005
- Oftadeh, Javad. 2016. *Analysis of social networks (together with the training of Nodaixal and Gefi network analysis software)*. Tehran: Sanieh. [in Persian]
- Peek, Gert Joost, and Louw Erik. 2006. A Multi-Disciplinary Approach of Railway Station Development. The Architecture Annual: Delft University Of Technology, Amsterdam.
- Rafiyan, Mojtaba, and Hadith Asgari Tafreshi. 2009. Investigating the "land supply pattern" in the areas around the metro station using the audience-oriented perspective, a case study of the Sadeghieh station. *Urban Management* 7(24): 81-93. https://ensani.ir/fa/article/61374. [in Persian]
- Ranger, Kulveer. 2009. *Interchange Best Practice Guidelines*. London: Transport for London.
- Rezaei Farei, Amirhasan, and Aliakbar Ehterami. 2019. Classification of the risk of surface structures and investigation of the performance of in-situ piles in reducing settlements caused by digging subway tunnels in urban areas (case study: Tabriz subway). *Transport* 5(1): 97-119. doi: 10.22075/JTIE.2018.13548.1278. [in Persian]
- Salmani, Saeed, Khalil Vlizadeh Kamran, and Bakhtiar Feizizadeh. 2018. Developing Urban Smart Network Based on OMS Data for Crisis Management in GIS Environment in the Abrasan Subway Station. *Transport* 10(2): 233-243. [in Persian]
- Samanifar, Sousan, Mohammad Khazaei, and Abbas Verij Kazemi. 2019. Investigating the views of Tehran subway passengers regarding the state of its environmental graphics (Case study: Tehran Metro signs and symbols system). *Visual and applied arts* 12(23): 5-24. https://www.sid.ir/paper/375563/en. [in Persian]
- Sampaio, Breno Ramos, Oswaldo Lima Neto, and Yony Sampaio. 2008. Efficiency Analysis of public transport systems: Lessons for instutional Planning. *Transportation Research Part A: Policy and Practice* 42(3): 445-454. https://doi.org/10.1016/j.tra.2008.01.006
- Saygaonkar, Prathamesh , Mansha Swami, and M. Parida Prof. 2016. Station area design approach for enhancing multimodal urban transport system, New Delhi. *Transportation Research Procedia* 17: 16-31. https://doi.org/10.1016/j.trpro.2016.11.057
- Transportation Research Board. 1999. Transit Capacity and Quality of Service Manual. Kerjcie and Morgan Determining Sample Size for research activities. *Educational and psychological Measurement* 30: 607-610.
- Turner, Alasdair. 2007. "UCL Depthmap 7: From isovist analysis to generic spatial network analysis." In *New Developments in Space Syntax Software* edited by Turner, A. Istanbul Technical University, Istanbul. http://www.vr.ucl.ac.uk/events/syntaxsoftware07/turner.pdf.
- Tyrinopoulos, Yannis, and Constantinos Antoniou. 2008. Public transit user satisfaction: Vriability and policy implications. Transport Policy 15(4): 260-272. https://doi.org/10.1016/j.tranpol.2008.06.002
- Van Nes, Akkelies, and Claudia Yamu. 2007. "Micro scale spatial relationships in urban studies. The relationship between private and public space and its impact on street life." In *Proceedings Space Syntax. 6th Interna-*

tional Symposium, Istanbul. http://www.spacesyntaxistanbul.itu.edu.tr/papers%5Clongpapers% 5C023%20-%20 VanNes%20Lopez.pdf.

- Van Nes, Akkelies. 2012. "The one- and two-dimensional isovist analyses in space syntax." In *Exploring the Visual Landscape; Advances in Physiognomic Landscape Research in the Netherlands* edited by Nijhuis, S., van Lammeren, R., van der Hoeven, F., 163-184. http://dx.doi.org/10.4233/uuid:fe6698ae045c-436b-945b-c61c4b0437e4.
- Xu, YJ., X. Bai, and KF Chu. 2016. "Underground space in metro area: constituent, influencing factors and improving strategies of the spatial vitality." *17th World Conference ACUUS 2020 Helsinki*. IOP Conf. Series: Earth and Environmental Science 703 (2021) 012016. IOP Publishing. doi:10.1088/1755-1315/703/1/012016.
- Young, K., J. Chung, E. Kong, H. Shin, and J. Heo. 2015. *A study on the design methodologies for activating*. Jiang, Claramunt, Klarqvist.
- Zheng, Wensheng, Nanqiao Du, and Xiaofang Wang. 2021. Understanding the City transport System of Urban Agglomeration through Improved Space Syntax Analysis. I*nternational Regional Science Review* 45(2): 161-187. DOI: 10.1177/01600176211023879.

HOW TO CITE THIS ARTICLE

Haghlesan, Masoud. 2023. Optimizing the Spatial Design of Urban Metro Stations Using the Space Syntax Method. *Armanshahr Architecture & Urban Development Journal* 16(44): 45-62.

DOI: 10.22034/AAUD.2023.360784.2716
URL: https://www.armanshahrjournal.com/article_179185.html