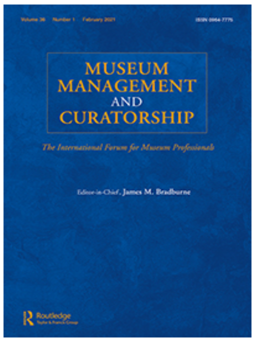

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ABSTRACT

Analysing the navigation behaviour in a built environment without a particular destination is a complicated issue when simulating pedestrian behaviour. This navigation is called exploratory navigation. This paper aims to investigate the spatial characteristics of a built environment which affect exploratory navigation. It focuses on visibility graph analysis (VGA) and uses the artificial neural network (ANN) for predicting navigation behaviours of visitors in museums. The movement data of visitors in the Islamic Revolution and Iran-Iraq War Museum (IRIIWM) in Tehran, Iran are collected from an observational study. The neural network analyzes the movement features of visitors and produces one single route containing all important movement characteristics of actual visitors. The results show that the network chooses its next target based on spatial visibility, visual perception, distance to a particular section, direction change, visual connectivity, and visual integration. The turn patterns and visual attractors also affect exploratory navigation.

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Visibility graph analysis; space syntax; exploratory navigation; movement behaviour; neural network; Islamic Revolution and Iran-Iraq war museum

Introduction

The movement pattern of pedestrians in a built environment is an important issue has been investigated in many studies. Predicting the movement patterns of individuals in a built environment with a source and destination has been explored by many researchers. However, navigation in the environment without a specific destination, namely exploratory navigation, has been rarely discussed. For instance, people in museums want to walk around and change their routes and target sections based on how they perceive the environment and spatial configuration (Wang, Lo, and Liu 2017). The spatial configuration of a built environment and its complicated spatial layout can affect pedestrians' movement pattern and the way they navigate through a particular space and their wayfinding behaviour (Omer 2016). The spatial organisation of a space affects social life; thus, it is very important to understand the relationships between spatial organisation and social life for improved design (Hillier 1996). The movement patterns of visitors in museums reveals the effects of architect designs on

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the visitors' navigation and movement behaviour. Visitors' movement behaviour also indicates where they go, what they see and where they spend more time and focus their attention. Analysing the movement patterns of visitors gives museum curators and designers insight into how visitors choose their route, where they pay attention and how they perceive the museum space. It is crucial for designers to be aware of these factors so as to understand the effect of their design on visitors' behaviour (Stephen Bitgood 2010; S. Bitgood 2010). In Iran, navigation behaviour of visitors in museums is one of the challenging issues which has been rarely examined by researchers. The effects of spatial configuration and the organisation of objects on the visitors' behaviour have often been neglected by the designers. One of the most challenging museums in terms of navigation is the IRIIWM. The sequential spaces, long axial lines, continuous and long routes, and linear circulation in this museum have made it an important museum for analysing navigation behaviours of visitors. This paper is intended to extract guidelines on the design of museum spaces by analysing navigation behaviour of visitors. These guidelines will help architects and designers to effectively evaluate their design concepts and to design museum spaces consistent with human behaviours.

Literature review

Movement patterns and navigation behaviour of pedestrians in a built environment is one of the key issues in pedestrian simulation models. Architects and designers have to be aware that their design decisions have a significant impact on the experience of visitors in a built environment. Understanding these correlations will help museum designers and architects to predict the results of their design decisions on movement patterns of visitors. Today, there is an increasing concern about the realistic movement patterns of pedestrians and extracting important spatial factors affecting navigation behaviours. The spatial configuration of museums and spatial organisation of the displays can also affect the way visitors experience the museum and the way they navigate through the spaces. The optimal route in a built environment is not always the shortest one. Studies have shown that pedestrians often prefer to choose the most convenient route or the safest route rather than the shortest one. People explore a new environment based on the quality of the path, interesting objects near their location and other important factors related to their location (Millonig and Gartner 2009). Pedestrians navigate through a built environment in 3 ways: travel to a known destination, travel to a new destination, and exploratory navigation (Wang, Lo, and Liu 2017; Taylor 2009). Going from home to the workplace is an example of travel to a known destination. Going to new places and finding the routes using the guides like maps or other gadgets is an example of travel to a new destination. And going to a new museum and walking around to explore its spaces is an example of exploratory navigation (Wang, Lo, and Liu 2017). So far, many researchers have worked on wayfinding behaviour in environments with a particular destination (Zhou et al. 2016; Basiri et al. 2019; Sas et al. 2003; Mandel 2018; Devlin 2014). However, navigation behaviour within the built environment without a particular destination, namely exploratory navigation, has rarely been explored.

Many researchers have studied visitors' behaviour in museums (Christidou and Diamantopoulou 2019; Ji-Hyun Lee 2019; Robert Strohmaier, Sprung, and Nischelwitzer 2015; Joel Lanir et al. 2016; Rainoldi, Neuhofer, and Jooss 2018; Claudio Martella et al. 2016; Bronnenkant and Yalowitz 2009; Massimo Zancanaro et al. 2007). Some of the research have simulated pedestrians' movement and navigation behaviours in an environment and investigated the important factors affecting human movement and navigation behaviours (Natapov, Czamanski, and Fisher-gewirtzman 2016; Moussaïd, Helbing, and Theraulaz 2011; Wang, Lo, and Liu 2017; Ramamtitham 2017; J. Li et al. 2015; Borgers 2005). W.l. Wang, Lo, and Liu (2017) used a section-and-portal graph to show how different sections of the space have various walking potentials. In this graph, each space can be divided into subsections and these subsections are connected by the portals based on the space geometry. Using a section-and-portal graph, Wang presented a simulation model for the navigation behaviour of pedestrians. Researchers have applied the space syntax theory introduced by Hillier as an important tool to reveal the underlying effects of spatial organisation on visitor's movement behaviour and navigation (Tzortzi 2007). Space syntax theory is a tool for understanding the spatial configuration and spatial formation of an environment and its effects on human activity (Ostwald 2011; Tzortzi 2007). Braaksma and Cook (1980) used visibility graph analysis (VGA) to investigate visibility relationships between different units within the built environment (Hillier 1996). Visibility graph analysis (VGA) is one of the most intricate methods of space syntax theory. It is based on the intervisible locations and provides a quantitative analysis of visibility features in a built environment. It is a common way to represent what pedestrians can see and predict where they can go within the built environment (Hillier 1996). The other important approach of space syntax theory is the isovist. An isovist is 'the set of all points visible from a given vantage point in space' (Goss 1993; Benedikt 1979). Isovists have many geometric parameters such as compactness, area, perimeter, and people move within built environments based on these parameters and their visual fields (Dzebic 2013). Turner et al. investigated and developed this analysis by applying isovist approaches (Turner 2001). Using a set of isovists produces a visibility graph. Human wayfinding, navigation and patterns of space use is highly affected by the visibility graph features (Jan M Wiener et al. 2007; Doxa and Sullivan 2001; Franz and Franz 2005; Alasdair Turner and Penn 1999; N. Grasso et al. 2017; Rohloff, Psarra, and Wineman 2009; Dzebic 2013). Space syntax is an important tool that investigates how spatial layouts create different sociocultural meanings and how the spatial configuration of the space is correlated with movement patterns and navigation behaviours and interactions in a built environment (Tzortzi 2011; Penn 2001; Lazaridou and Psarra 2017; Hölscher and Brösamle 2007; Yun and Ook Kim 2007). Previous studies have focused on space syntax theory for analysing the spatial configuration and movement paths of pedestrians in a built environment. People interact with each other in complex spaces and they experience the spatial layout based on their visual fields. Visual perception is one of the most important stimuli that can influence an individual's movement pattern within a built environment (Batty 2001). Kali Tzortzi demonstrated that pattern of movement is correlated with the spatial layout of building spaces. The spaces with higher integration values have higher movement densities (Tzortzi 2014). Many researchers have simulated and investigated pedestrians' movement behaviour in a built environment considering the visual attractors (Wang et al. 2014), space visibility (Parvin, Min Ye, and Jia 2007; YING, LI, and GAO 2009), and gender differences (Jennifer Tropp Sneider et al.

2015; Bia Kim, Sewon Lee, and Jaesik Lee, 2007; Cashdan et al. 2016; Deborah M Saucier et al. 2002; Lovden et al. 2007). Some researchers have used the actual paths of pedestrians for simulating and analysing movement behaviour and the way visitors experience museum spaces and time spent on each space. To understand the complicated correlation between the spatial features of an environment and movement behaviours of visitors in a museum space, researchers have used observational data such as visitor's actual traces, mean occupation rate, mean viewing rate, and mean moving rate in each space and correlated these data to the spatial characteristics of the museum space (Salgamcioglu 2017; Tzortzi 2007). Tzortzi used actual movement paths of visitors and showed that spatial design of museums and visual integration play a crucial role in the route choice and movement behaviours of visitors. The physical features of museums influence visitors' behaviour and the choice of route and navigation (John Peponis et al. 2004). It also affects the pleasantness of the visit experience (Millonig and Gartner 2009; Turner 2001). Navigation and route choice decisions are affected by visual connectivity, and pedestrians' spatial behaviour is controlled by their visual field (Gibson 1950; Natapov, Czamanski, and Fisher-gewirtzman 2016; Weisman 1981; Kaynar 2005). Exploratory navigation and pedestrians' spatial behaviour are highly influenced by visual fields and visibility relationships of the spaces in an environment. The distance to a particular attractor and the attractor qualities affect pedestrian's movement behaviours (Wang et al. 2014). The other key factor in navigation behaviour of pedestrians is intelligibility. Intelligibility is the correlation between local and global features of visibility which affects human behaviour and is affected by the spatial features of the environment. Legibility shows whether the spatial organisation of an environment has a coherent pattern or not (Hossein Safaria, Fataneh Fakouri Moridania, and Sharifah Syed Mahdzar 2016; Emine Koseoglu and Deniz Erinsel Onder 2011; O'Neill 1991; Herzog 2003). The extracted important factors affecting navigation behaviours in exploratory navigation should be accurate and reliable. For this purpose, the simulated movement path should be the most similar route to the real traces of pedestrians. To analyse movement path of visitors, which is complicated nonlinear data, and to extract the important spatial characteristics of the museum, which affect navigation behaviour, this paper adopted a different approach and a more valid reference. Thus, the authors applied the neural network as a powerful tool for analysing the highly dimensional nonlinear data to predict movement pattern and navigation behaviour of visitors by producing a valid single route. By simulating the actual movement paths of visitors within the museum space, the neural network analyses and considers all complicated movement aspects and navigation features of the visitor's path and predicts the movement patterns of visitors in the museum space (in this case, IRIIWM). This single path is a valid reference for analysing and extracting the important spatial factors that affect navigation behaviour.

Islamic Revolution and Iran-Iraq war museum

The IRIIWM which is located in Tehran, Iran, commemorates Iranian bravery during the Iran and Iraq war. This museum is the largest museum of Iran and one of the largest museums in Asia which represents the contemporary history of Iran using modern technologies and tools and focuses on Iran-Iraq war (Figure 1).

Figure 1. IRIIWM, Tehran, Iran.

This museum is on a large scale and has seven halls and one terminal area which contains the war monument. The visual organisation of the spaces is designed to create long visibility axial lines during movement in its spaces (Figure 2). Circulation in this museum is completely linear and the spaces are sequentially and continually organised. Figure 3 shows the plan of this museum (Figure 4).

Figure 2. View of galleries at IRIIWM, which are sequential.

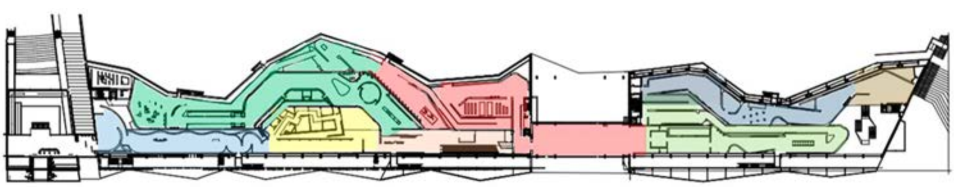

Figure 3. Plan of the IRIIWM, gallery area.

Figure 4. The spatial organisation of the galleries in this museum is sequential and continual.

Data analysis

Section-and-portal graph and space subsection

As mentioned in previous sections, a section-and-portal graph is a valid reference for analysing navigation behaviours and path choice within a built environment. According to Wang, pedestrians have to choose a special route in decision sections. In this graph, space is divided into subsections connected by the portals based on its configuration. There are four types of subsections, as shown in Figure 5.

Cul-de-sac section: is the section with only one portal.

Transit section: is the section that has 2 portals.

Decision section: is the section that has more than 2 portals.

Entry or exit section: is the section where people enter or exit the place.

According to the section-and-portal graph, in the IRIIWM, the spaces are divided into the aforementioned subsections based on their geometry, as shown in Figure 4. As indicated in Table 1, many spaces in the IRIIWM are considered to be transit sections. This is confirmed by the linear configuration of the spaces. There are also some decision sections which are the most important ones for analysing visitor movement patterns and navigation behaviours. This is due to the fact that in these sections, visitors have to pinpoint their next target and choose one specific route to reach that target. Hence, the way they move and navigate through the museum spaces depends on the decision sections. It is necessary, therefore, to consider these subsections for analysing visitors' movement behaviours and also for the museum design process.

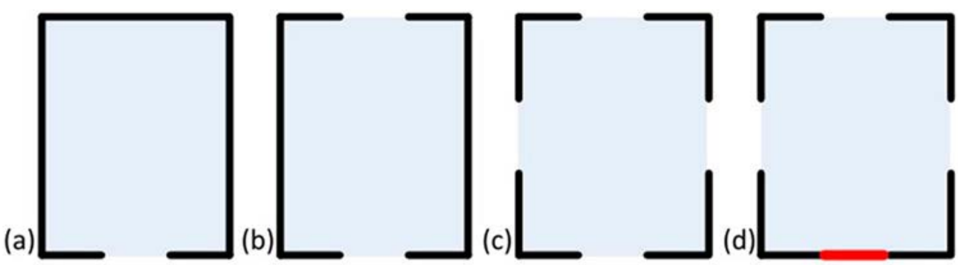

Figure 5. Space subsections: (a) cul-de-sac section (b) transit section (c) decision section (d) entry or exit section.

Table 1. Identification of different types of subsection in IRIIWM.

Section type	Section numbers
Cul-de-sac	15, 59
Transit	2,3,4,5,7,8,10, 12, 13, 16, 18, 19, 22, 23, 24, 26, 27,28,29,30, 32, 33, 34, 37, 38, 39, 40, 42, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 60, 61, 62
Decision	6, 7, 9, 11, 17, 20, 21, 25, 31, 35, 36, 41, 43, 58, 60
Exit or entry	1, 63

Space syntax and visibility graph analysis (VGA)

As mentioned in previous sections, space syntax is a theory that is related to spatial configuration and its effect on human behaviours. Space syntax is an abbreviated term for a method that quantitatively analyses the space configuration in a built environment. Visual fields affect visitors' movement behaviours. There are some environmental features affecting movement behaviours, such as visibility, connectivity and integration. In order to analyze visual access, Depthmap software is used to produce an organised analysis of the museum spaces. One significant element of Depthmap software is VGA. Considering all accessible locations in terms of visibility, VGA is an exhaustive method that analyses the visual access of the whole configuration. As indicated in Figure 7, visibility at the entry areas is low, and as visitors walk through the spaces in sequence, visibility gradually increases. In the central galleries and central bridge known as the Martyr Bridge which connects the different parts of galleries, visibility is at its highest, and eventually, in the final galleries, visibility is at its lowest (Figures 6 and 7).

Neural network analysis

Artificial neural network (ANN) is an important tool for modelling and analyzing complicated nonlinear data. Nowadays, ANN has become one of the powerful and valuable solutions for sophisticated high-dimensional functions (Figure 8).

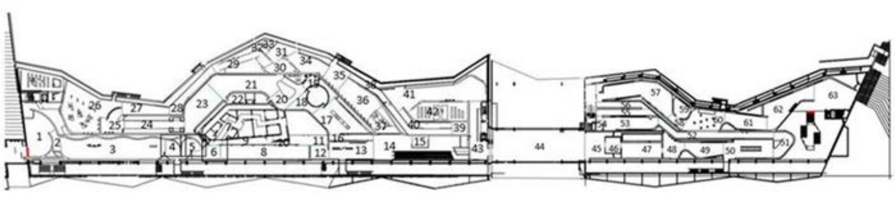

Figure 6. Space subsections in the IRIIWM. The museum spaces are divided into 63 subsections based on their geometry. Blue lines show the hypothetical portals in each section.

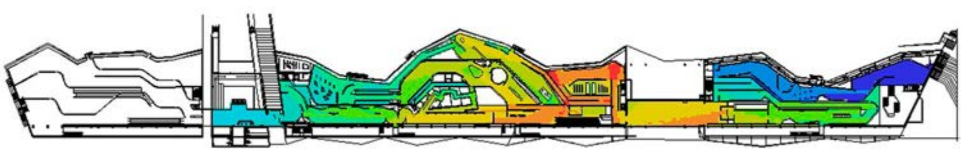

Figure 7. Visual integration analysis of layout of IRIIWM.

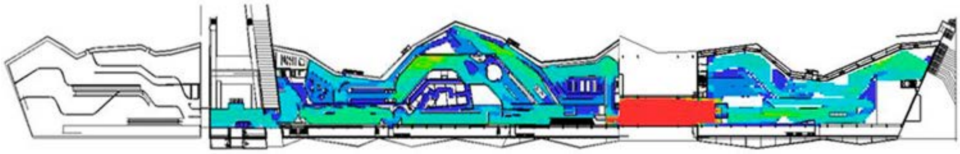

Figure 8. Visual connectivity analysis of layout of IRIIWM.

The purpose of this paper is to identify the important spatial factors of a built environment, in this case, the IRIIWM, which affects the movement and navigation behaviours of visitors. Considering the actual traces of visitors during their visit, ANN is applied to predict visitor's general movement path within the museum space. ANN produces a valid single route, and the important spatial features of the museum space affecting navigation behaviour should be extracted based on this single path.

Data preparation and simulation process

At the first step, in an observational study, the actual movement path of 40 individuals (25 men, 15 women) is recorded during their visit to the IRIIWM. Each movement path contains many different points representing an individual's location every 10 s, and the stop points and route changes in each region are identified. Each point is identified by its coordinate (X, Y), and the location of each individual at each point of his/her itinerary should be defined in the recording path process. The neural network should be trained by the actual movement traces of 40 visitors in the IRIIWM in order to learn all complicated movement features of the visitors. The neural network predicts and extracts the movement patterns and navigation behaviours of visitors by analysing the important features of these traces. The MATLAB software is used to analyse the movement data. In order to analyse the movement data by the neural network, the museum plan should be prepared and entered into the image processing environment of the MATLAB software. To this end, the museum plan is converted to an image which contains the black and white points. The black points indicate the walls and collections displayed within the museum spaces and white points show the spaces through which the visitors can walk. In order to enter the MATLAB software, the plan of the IRIIWM is converted to an image with the dimensions of 461×3100 pixels, where each pixel is equal to 1/10 m. As the second step, the movement points of each visitor are recorded every 10 s. Figure 9 shows the movement path of 40 visitors by 40 different colours.

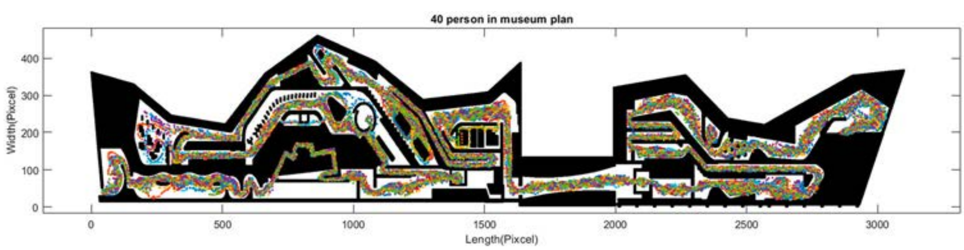

Figure 9. Movement path of 40 visitors in IRIIWM. Each colour indicates the movement path of an individual.

The points with almost the same coordinate parameters show the same location and thus, the time spent in that specific location. The time spent in each location can be calculated through the number of points in that specific location multiplied by 10 s (sample time). For instance, Figure 10 shows that the visitor has spent 2 min in the war simulation gallery and 50 s in front of the map of Iran. The present study investigates the navigation behaviour of visitors exploring the museum space. ANN is applied to learn the visitor's movement traces and also all characteristics of the visitor's paths to predict the movement pattern and navigation behaviour of visitors during their visit. For this purpose, the movement traces of visitors are taught to the neural network and the network predicts the visitor's location in the next step considering the current and previous locations of the visitor. Considering all features of actual movement traces and different navigation styles of visitors and regardless of the spatial characteristics of the environment, the authors used a radial basis function (RBF) network. RBF is an artificial neural network which has only one hidden layer with nonlinear functions. This network has three layers. The first layer contains input nodes and the second layer is a hidden layer with nonlinear high-dimensional functions. Finally, the output layer is a linear function which indicates the network solution per input. Figure 9 represents the RBF neural network used in this paper.

The network input contains a sequence of a visitor's movement traces. The whole set of data is divided into 3 parts where 70% are used for training, 15% for validation, and the last 15% for testing. To enable the network to predict the next step, the input data should be properly prepared. Thus, by entering the previous six steps as input data, the next step is the network output. Table 2 shows the sequence of input and output data (Figure 11).

The input data contains two characteristics, i.e., (X, Y) coordinate of each movement points traversed by visitors. Table 2 should be drawn for Y coordinate, as well as for X

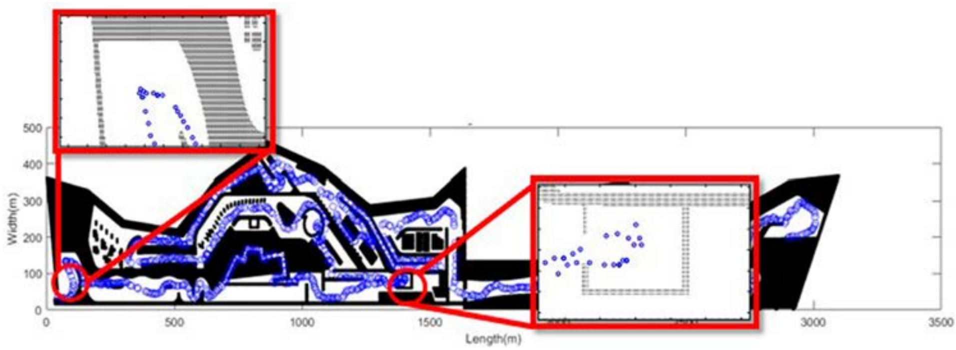

Figure 10. Movement path of one visitor in IRIIWM. Blue points show the location of the visitor every 10 s.

Table 2. Sequence of input data for prediction of next step.

	Input data							Output
Step	$X(t)$	$X(t-1)$	$X(t-2)$	$X(t-3)$	$X(t-4)$	$X(t-5)$	$X(t-6)$	$X(t+1)$
7	$X(7)$	$X(6)$	$X(5)$	$X(4)$	$X(3)$	$X(2)$	$X(1)$	$X(8)$
$N-1$	$X(N-1)$	$X(N-2)$		….			$X(N-7)$	$X(N)$

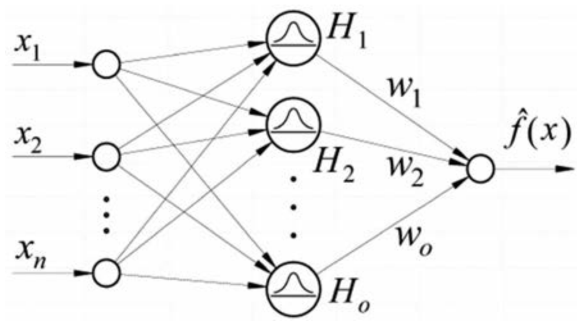

Figure 11. RBF neural network.

coordinate. Hence, the current neural network has 12 input and 2 output data. The applied neural network has 2081 radial basis cells in its hidden layer. The number of these cells is based on trial and error to reach the most reasonable amount in order to assimilate the output data with the actual path of visitors. After training the network with these different movement paths, the trained network should produce a valid single path based on these movement data, which can be a valid reference for analysing and extracting the important spatial factors of the museum space affecting exploratory navigation and movement behaviour. Because this single path contains all important movement characteristics of visitors during their visit, in this simulation, the mean square error is 0.2180 which is an acceptable value (Figures 12–14).

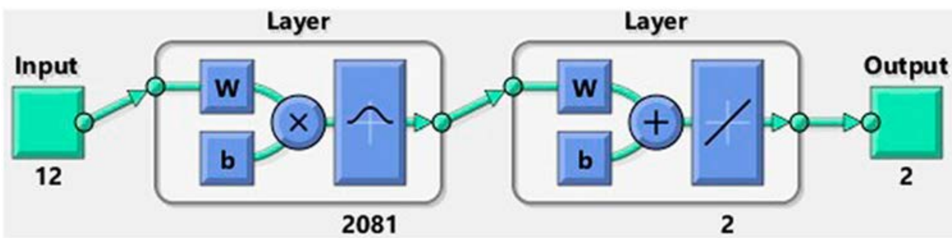

Figure 12. Structure of neural network applied in this paper.

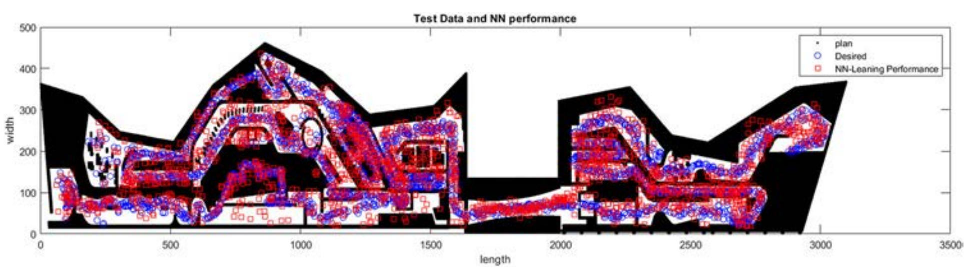

Figure 13. Test data in NN simulation (the blue points show the visitor's path and the red points show the NN path).

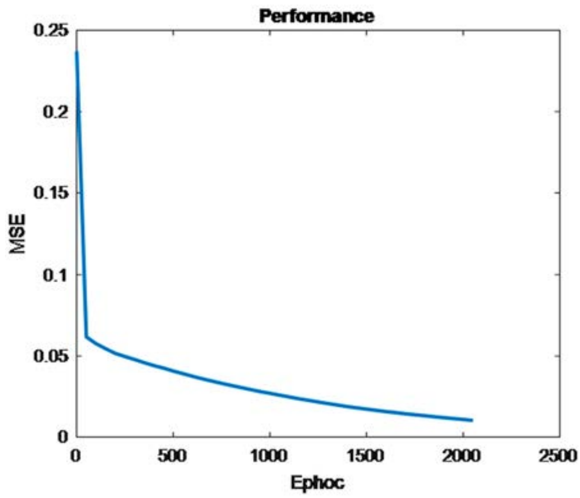

Figure 14. Network performance: the mean square error is 0.2180 in this simulation.

Results

As mentioned in the previous section, the neural network output is a movement path which contains a series of points. In some locations, these points are dense and close together and conversely, in some other locations, these points are highly dispersed. The dense regions indicate high stop time and low velocity of the network while moving through that specific region, and the regions with high dispersion points indicate the high velocity of the network while moving through those regions. This means that the network spent less time on that specific region and the probability of ignoring and missing this space by the visitors is usually high. Hence, the network traversed movement path is an exact result of the visitors' actual movement path and the important spatial features of the museum space affecting exploratory navigation, and movement behaviour can be extracted as a single route. Figure 15 shows the result of the neural network and the predicted movement path. As mentioned in the section-and-portal graph, the decision sections are important for analysing movement patterns and navigation behaviours. Thus, the network movement behaviour is analysed in the IRIIWM, specifically in

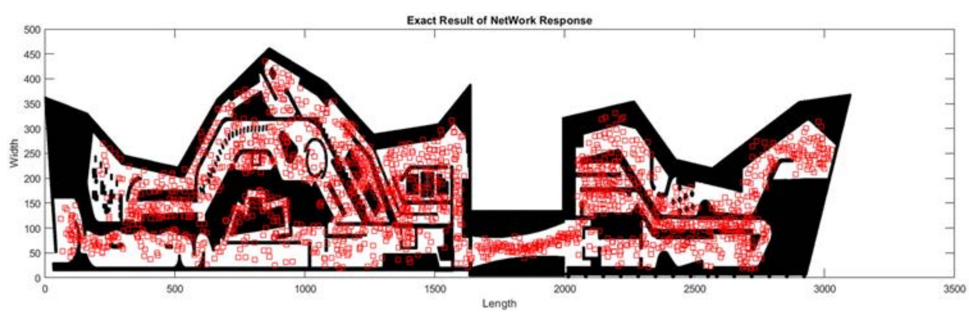

Figure 15. Network response to input data (the red points show the movement path predicted by the network); the dense regions indicate the high time spent in that region.

the decision sections. Also, the visibility analysis in space syntax theory performed by Depthmap software is used to identify and extract the spatial characteristics of the museum space affecting exploratory navigation. The visit style in the IRIIWM is completely informal and exploratory, which is similar to the Tate Gallery in London. The first decision section in this museum is section 6. As can be seen in Figure 13, the network chooses section 7 as its next target which is the nearest one to section 6. In section 9, the network chooses the nearest section as its next target once more and moves toward the section. In section 11, the network chooses its next target from 2 sections of 8 and 12. The network chooses section 12 as its next target (Figure 15).

The reason for this choice may be due to the network tendency to move forward and avoid backtracking. In section 14, the network uses two routes which lead to sections 15 and 16, and it chooses the first one (the route which leads to the war simulation gallery) as its next target. This may be due to the network tendency to move in a direct path (Figure 16).

Thus, routes with a change of direction have the next priority. Another reason for this choice may be the direct axial visibility and extensive view toward this room, as shown in Figure 16a. In sections 17, 20 and 21 of this museum, the density of network points is high near the left side wall. This is due to the long straight axial line sight near this wall, and the network tends to keep moving in a straight line instead of sequential direction change. In the Tate Gallery, the major movement paths of actual visitors are in the main axis. The dispersion of points in room 22, the Hot and Cold trench gallery, is high. Thus, the probability of missing this gallery by the visitors is high, because this room is a closed space and is located along the galleries and in addition, it has low visibility values (Figure 17b). In section 25 of this museum, the network chooses section 27 as its next target. As can be seen in Figure 18, the density of networks points in section 27 is higher than section 26. In section 35, the network chooses between section 38, which is a corridor space, and section 36, which is the gallery of war weapons. The network chooses section 36 as its next target. This is due to the high visual integration of this gallery and also due to the attractiveness of the war weapons for the visitors. In section 44, known as Martyr bridge, the density of network points is high, which indicates the highest stop time in this section, as shown in Figure 17. In VGA analysis, this section has high visual connectivity, which is shown by the colour red in Figure 9. Similar to the Tate Gallery, the patterns of space use and the results of VGA are almost identical. In section 59, which is a cul-de-sac section, the high dispersion of network points can be seen. This is due to the location of this gallery in the whole layout and the low integration value of this area. Based on these simulation

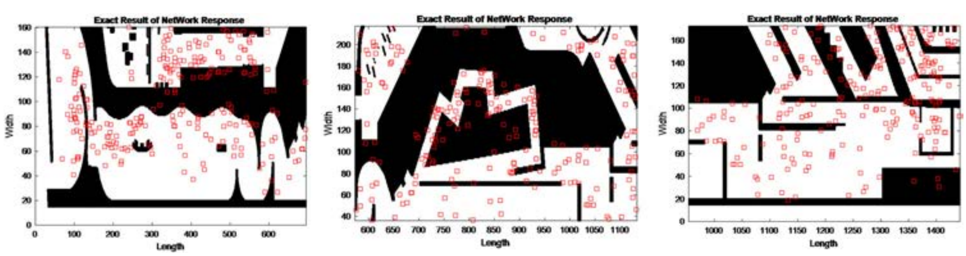

Figure 16. Navigation behaviour and movement points of NN in sections 1–16.

(a) (b)

Figure 17. War Simulation room (a), Hot and Cold trench gallery (b).

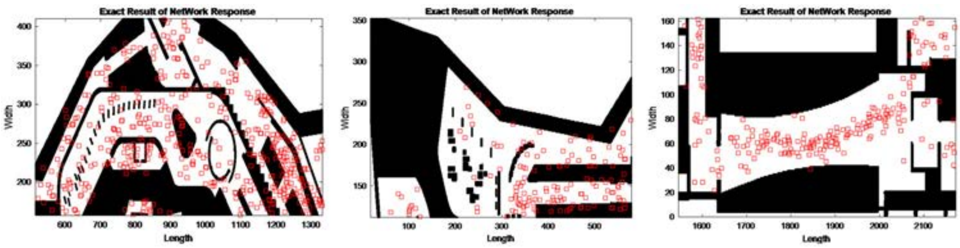

Figure 18. Navigation behaviour and movement points of NN in sections 17–44.

results, the important spatial factors of museum space affecting exploratory navigation and movement behaviours are described in the next section (Figure 19) (Table 3).

Discussion and conclusion

It is very important to analyse movement patterns and navigation behaviours of visitors of museums, which can help museum designers to improve their designs and evaluate their design ideas. Today, in Iran, the lack of knowledge about visitors' navigation behaviours in the design of museums have caused serious problems for visitors of these museums. Neglecting the spatial factors affecting visitors' behaviours has negative effects on the quality of museum spaces and also visitor satisfaction. This paper investigated the important spatial factors of the museum space, which affect exploratory navigation. The neural network is used as a powerful tool for analysing the nonlinear data obtained from the observational study. The actual movement path of 40 visitors in the IRIIWM was recorded by an observational study. MATLAB software was used to simulate the movement paths and produced a valid single route considering all important movement features of these actual paths. This single path contained a series of points. In some regions, these points were dense, and in some other regions, they were completely dispersed. The network movement behaviour can be reliable for analysing and extracting the important spatial factors affecting exploratory navigation. A section-and-portal graph was used as an

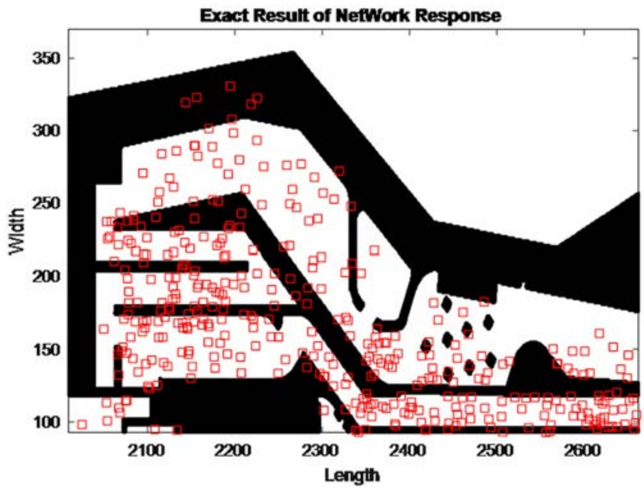

Figure 19. Navigation behaviour and movement points of NN in sections 44–59.

Table 3. General results of the Neural network simulation and Visibility graph analysis.

Reasons for high/low density	Depthmap analyses	Neural network analyses	Section number
• Nearest section to the last section • Winding path of the gallery stimulates curiosity	High integration value	High density of network's points	7
• Tendency for moving forward • Avoiding backtracking	High integration and connectivity value	High density of network's points	12
• Tendency to move in a direct path • Attractiveness of war simulation gallery • Direct axial visibility • Extensive view	High integration value	High density of network's points and low velocity of movement	15
• Long straight axial line • Tendency to keep moving in a straight line	High integration value	High density of network's points near the left side wall	17.20.21
• Hot and Cold trench gallery is located along the main route and hard to identify • Close space • Low visibility values	Low integration value	High dispersion of points High velocity of movement	22
• High visibility values	High integration and connectivity values	High density of network's points	27
• High visual integration • Attractiveness of war weapons for Iranian visitors	High integration value	High density of network's point	36
• High visual connectivity • Martyr bridge acts as a main connection between two parts of the galleries	High connectivity value	High density of network's points Low velocity of movement	44

important reference for examining exploratory navigation. Thus, in the IRIIWM, the spaces were divided into subsections and network movement behaviours were specifically analyzed in decision sections. Referring to VGA results, the visual integration and visual connectivity analysed by Depthmap software are the important parameters of the spatial environment affecting exploratory navigation. Examining neural network simulation and VGA results simultaneously revealed that in the decision sections where the network has to choose a target section among multiple choices, some spatial factors were entirely determinative. The results showed that spatial visibility is an important factor for navigating through a built environment without a particular destination, namely exploratory navigation. The visitors prefer the sections with high visibility, meaning that the probability of choosing the sections with high visibility is higher than other sections. There is a comprehensive correlation between visual perception and navigation behaviour. Visitors prefer to move through their line of sights, and the sections with high visibility axial lines are preferred. The other important factor affecting visitors' navigation in museums is the visual integration. As the integration value is increased in a specific section, the visitor's spatial cognition is increased and thus, the probability of choosing that section by visitors will be increased. As can also be seen in the Tate Gallery, the actual movement paths of visitors were denser in the spaces with a high value of visual integration. Visitors also tend to move forward in the space. As the direction change is increased in terms of the angle, the visitor's tendency to choose that specific route is decreased. They also prefer to choose the sections near their current location. In other words, the nearer the section, the more likely the section will be chosen. However, in the Tate Gallery, the major movement paths of visitors were through the main axis that was a continuous and long hall. The other important spatial factor affecting exploratory navigation is visual connectivity. High visual connectivity indicates an extensive visual field towards different directions in an environment. Sections with greater visual connectivity are preferred over other sections. There are also some other factors, such as the attractiveness of the displays, which may affect the way visitors move through the museum spaces. In general, the museum designers have to consider visual perception as a key factor in visitors' navigation behaviours. Understanding these important spatial factors helps the designers to consider the importance of the spatial configuration in navigation behaviours. In future work, the authors aim to consider the demographic and personal characteristics of visitors such as age and gender and also other personal aspects of visitors such as feelings. Environmental elements such as landmarks will be considered for training the neural network. Thus, by analysing the network output, the other important factors will be explored which affect movement and navigation behaviour in the museums.

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