Bagh-e Nazar

Bagh-e Nazar, 19(110), 21-34/ Aug. 2022
DOI: 10.22034/BAGH.2022.305973.5009

Persian translation of this paper entitled:
متدولوژی متکی بر طراحی در محیط مجازی خاص، جهت تدوین
ارتباط کیفیت فضایی و ساختار فضایی
is also published in this issue of journal

Original Research Article

Design-Based Methodology in a Specific Virtual Environment to Develop a Relationship between Spatial Quality and Spatial Structure*

Arash Hosseini Alamdari[1], KhosroDaneshjoo[2**], Mansour Yeganeh [3]

1. Ph.D. Candidate, Faculty of Art, Tarbiat Modares University, Tehran, Iran.
2. Assistant Professor of Architecture Department, Faculty of Art, Tarbiat Modares University, Tehran, Iran.
3. Assistant Professor, Department of Architecture, Faculty of Art, Tarbiat Modares University, Tehran, Iran.

Received: 22/09/2021 ; accepted: 17/02/2022 ; available online: 23/07/2022

Abstract

Problem statement: The relationship between spatial quality (spatial preferences) and spatial structure has been confirmed, and many studies have been conducted to determine the relationship between these two important architecture variables. However, the results of studies are often inconclusive and there are no quantitative and consensual theories about the relationship between these two variables due to the intrinsic complexity of both variables and the complexity of the relationship between them.

Research objective: This study proposes a new method for discovering and formulating the relationship between spatial preferences and spatial configuration and tests the accuracy and efficiency of this proposed method.

Research method: In this methodology, a unique virtual environment was created to allow continuous changes and design in the environment and controls of the intervening variables. Experts wereasked to design and increase the quality of space in this environment. The process of changing the spatial structure variables during the design process, and improving the spatial quality wereexamined. Then, the relationship between these two indicators wasexplained.

Conclusion: According to the results, the proposed methodology performs well in finding the relationship between spatial quality and spatial structure. It also indicates a high statistical correlation between some isovist analyzes and the trend of increasing spatial quality. The results also show that places with more visibility and less visual connections, accessibility, and complexity are of higher quality in some space syntaxes.

Keywords: *Spatial preferences, Spatial structure, Isovist analysis, Virtual environment, Quantitative models of expression of spatial properties.*

Introduction

In architecture and environmental psychology, the physical properties of space have been recognized to affecthuman perception and emotions. Spatial quality is one of the most important perceptual indicators whose relationship with physical spacehas been the

* This article is taken from the dissertation of Arash Hosseini Alamdari entitled "Upgrading the Refuge-Prospect theory by improving assessment models of the perception effect of spatial configuration"; Which has completed in 2022 under the supervision of Dr. Khosro Daneshjoo and the advice of Dr. Mansour Yeganeh in the Faculty of Arts of Tarbiat Modares University, Tehran, Iarn.

** Corresponding Author:khdaneshjoo@modares.ac.ir, +989121162273

concern of researchers. Spatial quality is defined as the degree of desirability of space from a human perspective that affects their preference in choosing a position. One of the critical variables affecting the spatial quality of the environment is the spatial structure, which is often displayed as a two-dimensional plan and is one of the most robust tools for expressing the environment before construction. Some theories have tried to define the relationship between the two variables - spatial structure and spatial quality - but neither has become a quantitative and consensus theory.

The complexity of quantifying spatial quality and spatial structure seems to be one of the reasons for this. Another reason is the complexity of the relationship between these two variables, due to the human dimension and the phenomenological effect between the two variables, which is considered as a barrier to understanding and quantifying this relationship.

Questions and hypothesis

The question that arises in this study is whether a more effective methodology can be developed to find the relationship between spatial quality as a variable based on human perception and spatial structure as a physical variable.

The following hypothesis is proposed in response to the above question:

A more effective methodology can be developed to find the relationship between spatial quality and spatial structure by relying on the design of designers as a process that enhances spatial quality on the one hand and the widespread use of modern technology and software on the other.

The proposed methodology is used to find the relationship between the two variables in a set of spatial structures.The strength of the results and the validity and reliability of the methodology are examined to test the hypothesis.

Literature review

• Qualitative Theories Linking Spatial Quality and Spatial Structure

Several theories have been proposed to define the relationship between spatial structure and spatial quality. By compiling a series of these theories, Hildebrand in 1991 tried to explain the spatial desirability of the works of the famous architect Frank Lloyd Wright (Hildebrand, 1991). The results of Hildebrand's efforts are summarized in the Prospect-Refuge Theory. Hildebrand's theory is based on Appleton's Prospect-Refuge Theory. This theory attributes spatial quality to the possibilities provided by the spatial structure to see (prospect) opportunities and danger, as well as escape and access (hunting and non-being hunted) (Appleton, 1975/1996). Other popular theories in this field are Kaplan's Information-Processing Theory and Berlyne's Theory of Arousal, both of which try to define environmental desirability based on information in the environment and how it is perceived and accessed (Kaplan & Kaplan, 1989; Berlyne, 1951). Hildebrand also incorporated these theories into the new version of the Prospect-Refuge Theory (Hildebrand, 1999).

The extended version of the Prospect-Refuge Theory seems to have been accepted by many designers as a guide to designing the ideal environment in the last two decades (Kellert, 2012; Lippman, 2010). The influence of these theories is evident in many of the designs of designers around the world today, such as Alvar Aalto, Glenn Murcutt, Jørn Utzon, and Peter Zumthor (Gallagher, 2007). It is worth noting that the theories of Hildebrand and Appleton are all qualitative and the results of the tests available to evaluate the validity of the use of these theories in design are qualitative even though the architecture community has accepted their philosophical foundations (Sanagar Darbani, Monsefi Prapri, Taherkhani & Hajifathali, 2019).

As noted, the relationship between spatial quality and spatial structure has been recognized. Qualitative theories address the relationship in general. However, it is worthwhile to refine and quantify this relationship. According to Ward, qualitative researchers may criticize the quantification of qualitative data and suggest that doing so would undermine the value of the features that distinguish qualitative data, narrative layering, and textual meaning. However, evaluation by scientific institutions (and its policy implications) requires the data to be presented in a scientific framework (Ward, 2010). Extensive urban and environmental policy-making is not possible without the quantification of variables. Quantification also allows software development that aims to help designers design the environment more optimally. In any case, the role of the designer will never be lost in this direction, just as the role of structural designers is still vital after the development of capable structural design software (Shokohi Dehkordi, Hashemnejad & Ikhlasi, Saleh Sadeghpour, 2013).

• Common methodology for quantifying spatial quality and existing problems

There is currently no standard, comprehensive, and consensual methodology for quantifying spatial quality. Moreover, it does not seem to be easy to provide a quantitative and numerical standard for spatial quality, given the breadth of variables affecting it and the phenomenological nature of the concept. Researchers typically quantify individuals' reactions to a limited set of stimuli using self-report questionnaires or directly examine individuals' reactions. One of the weaknesses of self-report questionnaires is the need to interpret emotions into a set of answers. Perceived quality is an inner matter that is affected by the knowledge of individuals as well as their current psychological and emotional state and is often perceived subconsciously and affects their behavior. Interpreting these emotions to the consciousness requires a high level of understanding of one's emotions, and this interpretation is usually not accurate. So, methodologies that rely on individuals' behavior to measure their emotions are often more accurate than methodologies that rely on individuals' expressions. It should be noted that measuring and quantifying behavior adds additional complexity to the research and, consequently, drastically reduces the reliability of each test. Due to the low reliability of conventional methodologies, achieving acceptable results requires performing a significant number of tests with multiple stimuli. Repetition of the process of measuring people's emotions after applying each stimulus makes the study time-consuming and increases costs, the respondent's fatigue, and thus reduces the accuracy of the study. On the other hand, the preparation of multiple stimuli with controlled and measured spatial structures poses another significant problem for researchers due to the diversity of tests required.Ifreal spaces are used, controlling environmental intervening variables and individual mobility would be problematic. Validity is also reduced due to the inaccurate transfer of spatial structure to the individual if environment visualization tools such as photographs or images are used. Controlling intervening variables recorded in visualization tools may also require image correction, which is another cost to the researcher.

Another issue that is discussed in such studies is the choice between real and virtual environments for conducting tests. The real environment has a more significanteffect on arousing one's emotions than the virtual environment, but it is much more challenging to control intervening variables in the real environment.On the other hand, modifying some variables (specifically environment structure variables) is not easy and requires multiple environments. Another challenge that the researcher faces in such cases is finding appropriate environments. The virtual environment provides more desirable possibilities for controlling the structure as a desired independent variable and more control over the intervening variables. Studies in recent years show the generalizability of results obtained in virtual environments to the real world with acceptable accuracy (Heydarian et al., 2015; Portman, Natapov & Fisher-Gewirtzman, 2015; Smith, 2015; Zhang, Kim, Shih, Koo & Cha, 2017. That is why virtual environments have recently been increasingly used to quantify the perceived quality of the environment. However, despite the possibilities of the virtual environment, the necessity of creating different environments by experimenters, presenting these environments to different people, and measuring the emotional effects of each environment by individuals requires substantial practice. The dispersion of the methodologies used to quantify the spatial quality in the studies conducted to measure the Prospect-Refuge Theory and explain the variables affecting it until 2016 can be seen in Fig. 1.

- **Quantitative models of expression of spatial properties**

The spatial structure should be quantified using models to quantify its effects on humans. These models are often complex mathematical structures defined by spatial properties. An optimal model interprets the main qualities of the environment into quantitative variables while being simple. Researchers have proposed different quantitative models of expression of spatial properties to achieve this. One of the most widely used and popular models among researchers is isovist. Isovist, referring to the polygon properties visible from an observation point, was proposed by Benedict as a basic and objectively identifiable element for quantifying the environmental properties (Benedikt, 1979). Researchers have paid close attention to isovist due to its strong semantic and structural relationship with human perception in the environment. Quantitative analyses such as area, perimeter length, number of vertices, and length of open or closed boundaries can be measured for each isovist. These basic quantitative descriptions, together, can explain more complex visual features of the given point. Since the definition of isovist, several attempts have been made to explain the relationship between the resulting variables and the perceptual properties perceived in the environment (Ostwald & Dawes 2019). Empirical evidence from many studies suggests that the spatial properties obtained from isovist points are consistent with the experience and behavior of people in space in reality (Benedikt & Mcelhinney, 2019; Xiang & Papastefanou, 2019; Aknar, M. & Atun, 2017; Esfandiari & Torkashvand, 2020).

Different researchers have developed various variables based on isovist, each of which has attempted to explain a particular spatial property and is sometimes very close in meaning. To organize these concepts, Franz and Wiener classified isovist variables based on four basic spatial properties, including spaciousness, openness, complexity, and order (Franz & Wiener, 2005). This classification has been accepted by many researchers.

Turner et al. defined and developed the visibility graph analysis (VAG) to describe spatial propertiesbetter and quantitatively express the characteristics of the environment's isovists (Turner, Doxa, O'Sullivan & Penn, 2001), (Fig. 2). This methodology considers a network of points in space and calculates isovist relationships and variables for each point in the network that can be considered as an observation point. It then presents the statistical values of the set of these isovists as a measure of understanding spatial properties. For example, if the average area visible from any observation point in space is relatively large, the high-dimensionality and, consequently, the feeling of openness can be attributed to the space. This approach provides more complex secondary estimates such as revelation and cluster coefficiency (Amini Behbahani, Gu & Ostwald, 2017).

This study attempts to select and use a set of visibility graph analyses, which is equivalent to the spatial properties expressed by Turner et al. (2001) and is used to express the four main variables of space. Table 1 shows these variables.

- **Efforts to quantify the relationship between spatial structure and spatial quality**

Various quantitative models of expression of spatial properties have been used to quantify the spatial structure and understand the relationship between spatial quality and spatial structure. Some of these

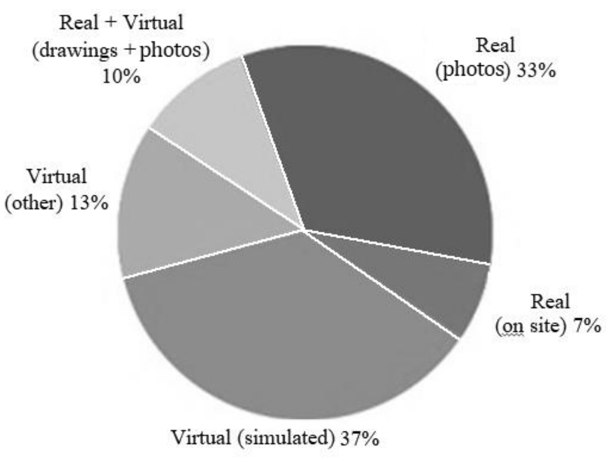

Fig. 1. The dispersion of methodologies used to measure spatial quality. Source: Dosen & Ostwald, 2016.

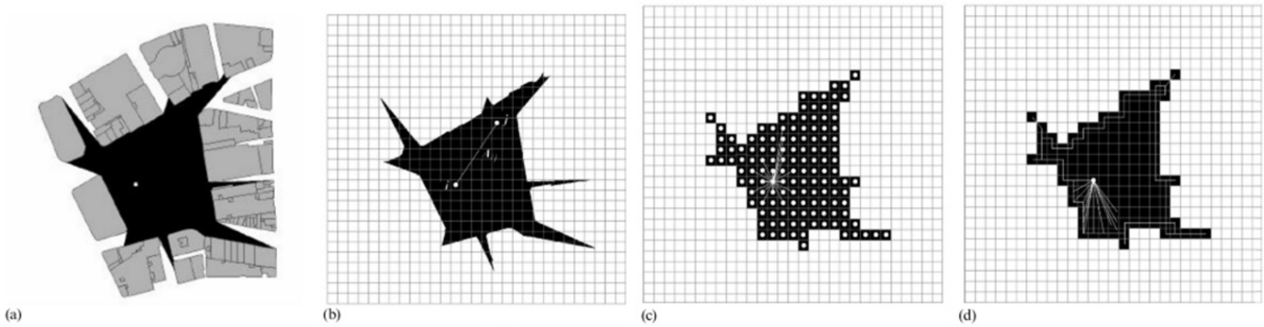

Fig. 2. Vision graph analysis creates a network of isovists. Source: Franz & Wiener, 2005.

models are space syntax, depth map, shape grammars, and fractal analysis.

Stamps may be the first researcher to try to quantify this relationship. He proposed the Prospect-Refuge Theory to study the desired environmental characteristics and the use of isovist analysis to examine the spatial quality (Stamps, 2006). He examined more than 15,000 environmental samples and used 25 isovist variables. According to Stamps, the most reliable isovist analyzes are isovist area (neighborhood size), roundness (coefficient of roundness), distance from the observation point to the isovist boundary (mid-wall distance), and boundary predictability (revelation) that can be used to measure environmental perceptions used in the Prospect-Refuge Theory and spatial quality. He also argues that the only feature that affects spatial desirability is the type of venues, including natural, urban, and indoor (Stamps, 2008).

Following Stamps' studies, the use of isovist analysis to quantify spatial structure concerning spatial quality based on isovist harmonized philosophical roots and theories of spatial quality - nature based on the observer's local position and reliance on observer visual information became widespread, with a review of studies on the Prospect-Refuge Theory and spatial quality measurement in 2016 suggesting that of the 14 studies conducted, 13 used isovist analysis (Dosen & Ostwald, 2016).

Other studies to explain the relationship between spatial quality and isovist analysis include studies by Sailer & Psathiti (2017) to explain the relationship between environment and seating preferences, by Hwang and Li to quantify the effect of window position and ceiling height on spatial quality, and by Oswald & Dawes to explain the spatial quality of Hollyhock House designed by Frank Lloyd Wright using isovist variables (Hwang & Lee, 2018; Ostwald & Dawes, 2020).

Theoretical foundations

- **Proposed methodology**

Since previous methodologies had some problems, including the high cost of multiple tests and low reliability and validity, a new methodology is proposed to measure the relationship between spatial structure and spatial quality. This methodology is based on constructing and using a specific virtual space. This virtual space allows the user to modify and design the space from the inside while experiencing the space. The tools provided for this design should be such as to enable the space to be modified only gradually. Software is also required to record modifications made to the environment.

This special environment should be provided to trained designers, and they should be asked to modify the space from inside and increase spatial quality. Designers design the environment from the inside out and modify it slightly at every step. It is conceivable that designers in this design process produce a large number of spaces with small differences. It is also conceivable that spatial quality increases during the design given that the goal of increasing spatial quality is intended for designers. Finally, each of these design steps can be considered as an independent space with an increasing trend in terms of spatial quality. The spatial structure of the individual

Table 1. The secondary variables of isovist and visibility graph. Source: Authors, based on Karimi Moshaver, Hosseini Alamdari & Azad Ahmadi, 2013.

Visibility graph analysis (VGA)	The definition of isovist	Related spatial properties	Related isovist variables
Neighborhood size	The number of points that can be seen from the observation point	Spatial openness, the breadth of the vision	Isovist area
Special neighborhood size	The sum of the inverse squares of the distance of each point visible from the observation point	Openness, breadth of the vision, the variety of of the vision	Isovist area at the distance of any visible point from the center of vision
Openness	The number of points to the neighborhood invisible by the center of the observation point	Closeness and openness, visual mastery of space, visual coherence, visual communication	The ratio of open edge length to closed edge length
Mid-wall distance	The average distance of points in the observation point	The feeling of openness, the feeling of being in the center of space	Mid-wall distance
Nearest wall	The distance to the nearest point next to the wall	Spatial openness, vision openness, vision transparency	Distance to the nearest wall
Revelation	The biggest difference between the neighborhood size of a point and its adjacent points	Changes in the range of vision during motion, the degree of visual coherence, the mystery of vision	Not applicable
Jaggedness	The ratio of openness to the total number of central points	The jaggedness of the visible area, complexity in vision	The ratio of the total length of the open and closed edges to neighborhood size
Roundness	The number of boundary points in total points	Feeling of spatial roundness - as opposed to the jaggedness	The ratio of the length of the edges to the observation point
Cluster coefficiency	The ability to cross-view the points seen from the point	The ability to classify spaces into specific classes	Not applicable

spaces created must now be interpreted as a set of variables, and the process of changing these variables during design must be examined.

The proposed methodology has the following features:

- It measures the spatial quality from a design perspective;
- It produces a large number of environments with high-speed and low-cost;
- The spatial quality produced is determined comparatively and lacks a non-comparable measure;

Lack of need for a questionnaire allows designers to focus fully on the design process and better communicate the subconscious sense of the environment;

- Lack ofneed for a questionnaire dramatically reduces the cost and time of the study;
- Lack ofneed to build a set of environments as stimuli greatly reduces the cost and time of the study;
- Visual space makes it possible to control intervening variables such as light;
- Virtual space can be designed to be compatible with the tool for converting the spatial structure into quantitative variables. For example, in the present test, isovist variables are used to quantify space, and an attempt is made to use a spatial set whose properties are reflected as much as possible in the resulting isovist analysis;
- The design tool can be considered to reflect certain variables more. For example, in the present test, the effect of neighborhood size is reduced due to the constant volume of the environment to make the impact of other variables more prominent;
- It requires the researcher's high technical knowledge and familiarity with software such as Unity to conduct the study.

Methodology

• How to test the proposed methodology

Since the study proposes a new methodology, the test should examine the validity of the proposed methodology and identify its strengths and weaknesses. There is no standard method in practice for examining a new methodology. The proposed methodology is examined in such a way that through which a test is performed and the test results are examined from the following points of view:

- The test results are converted into graphs that can be qualitatively reviewed and provide a conceptual overview of the results. Examining these graphs is hoped to shed some light on the nature of the problems and the capabilities of the proposed methodology;
- The test results are evaluated statistically and quantitatively, taking into account its consistency with the qualitative method;
- The test validity and reliability are checked using reliability tests and validity discussions;

The test method is assumed to be correct, and the obtained results are analyzed to understand betterthe phenomenon being tested. At this stage, obtaining new results on the one hand and matching the results with the background knowledge of the subject, on the other hand, are considered signs of the correctness of the proposed methodology.

The proposed methodology was used to perform a test to assess the relationship between spatialstructure and spatial quality. The spatial structure in this test was quantified using isovist indicators. As discussed in the introduction of the proposed methodology, visual space with the possibility of a special design was used to quantify the spatial quality as well as create multiple spaces. Since the relationship between space size and quality had already been confirmed in studies by Stamps, the design tool in the virtual environment tried to be considered to limit the changes in this set of variables as much as possible (Stamps, 2008). Thus, an attempt was made to highlight the role of other variables concerning spatial quality and increase the possibility of recognizing and explaining their relationship with spatial quality.

The test performed using the proposed methodology

The virtual environment was created by first-person perception using the Unity game engine and was provided to the designers. The overall level of the test environment was similar to a small museum measuring 729 m^2 in an 18 x 18 meter square shape consisting of 1. 5 x 1. 5 meter spaces (approximately equivalent to the minimum of an independent space). The ratio of the environment - the length of the exterior walls in addition to the interior walls - to the area of the test space was planned to be similar to that of a museum (e.g.,Tehran Museum of Contemporary Art). So, 70 interior walls (each 1. 5 m long) were considered for the complex in addition to 72 perimeter walls that were fixed. These walls could be placed on the sides of the squares of space. The location of the primary walls was randomly determined by a computer (Fig. 3).

The final environment was similar to the first-person computer games. Designers could move around in this environment, change the angle of view by moving the mouse, look around in the visual space, and move freely in space by navigating the keyboard keys. They could also remove or add predefined walls by clicking them as they navigated and experienced the environment (Fig. 4).

Besides, a set of walls (i.e., 13) was fixed in the environment. It was not possible to place the wall in five places to prevent the creation of a general mental design in the mind of the designer and its implementation and force the designer to make a set of case modifications. The lack of a general cognitive design forced the designers to modify the environment step by step based on what they saw in the environment. The number of adjustable walls in the environment had to be constantly between 70 and 67 to limit the design speed. This was monitored by software. Furthermore, the total volume of the environment and the total number of walls were constant, which reduced the effect of variables concerning the space size.

23 final-year undergraduate students in architectural engineering were asked to start designing with the features defined in the visual space and increase the spatial quality of the initial environment, the walls of which were randomly placed by a computer. 23 is the minimum acceptable number of high-precision psychology tests based on APA criteria (Jhangiani, Chiang & Price, 2015). The behind-the-scenes environment program, developed by the Unity game engine and the C # programming language, stored the removal and addition of each wall in the memory without the students' knowledge, thus recording the space design process. The results were presented to the university lecturers as referees, who were asked to

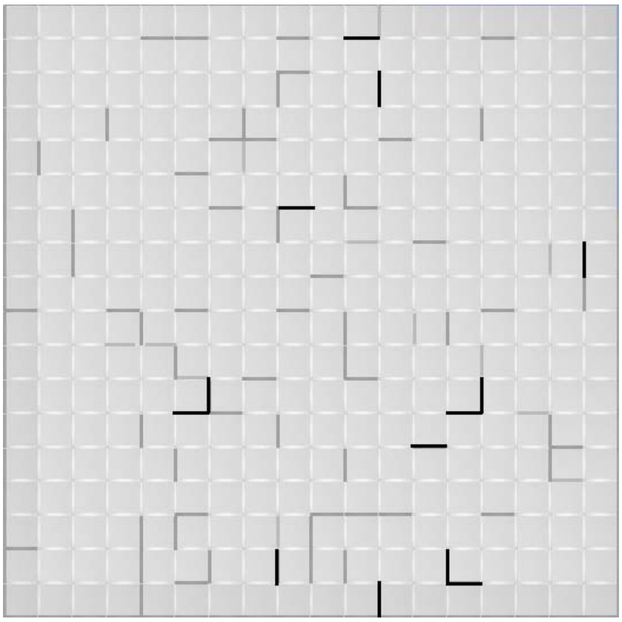

Fig. 3. Initial spatial design. Bold lines indicate fixed walls, light lines indicate adjustable walls, and white lines indicate possible places for the walls. Source: Authors.

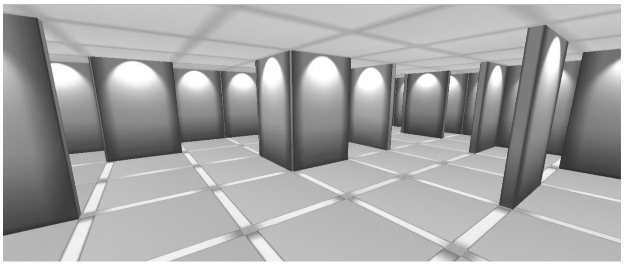

Fig. 4. A photo of the created virtual environment from the designers' point of view. The designer can navigate the environment in the form of the first-person game, remove the walls, or add white lines between the squares of the floor of the wall. Source: Authors.

select the most successful design in terms of improving the spatial quality. These 5 design processes were then reconstructed again by an independent program developed in C # based on the designers' saved motions. Theset of visual space points was measured at each step and after each modification of the environment of the isovist variables. These results were transferred to Excel software for quantitative analysis, and the correlation between the values and the design process was investigated by this software. Besides, values were converted to graphs using Excel to visualize changes in these variables during the design process (Fig. 5).

The graphs of each isovist variable given in Table 1, developed by the design process of each designer, were then aggregated into a graph, and a set of graphs was obtained that showed the trend of changes in each of the isovist variables during the design process of the designers and increased the spatial quality.

Results

• The success rate of the design process

- Visual analysis

As noted earlier, the modifications in the environment were made by the designers in the proposed test step-by-step with continuous and small modifications. On the other hand, the ultimate goal of the design was to improve spatial quality. So, spatial quality could be assumed to increase almost uniformly throughout the design process. According to this assumption, if one of the measured isovist variables decreases or increases almost uniformly, the test shows a positive or negative relationship between this variable and the spatial quality. The results were divided into classes concerning the main spatial properties expressed by Franz and Wiener (2005) and examined due to the existence of multiple graphs and for better analysis.

A set of variables related to spatial communication and spatial complexity can be seen in Figs. 6 & 7. Among the variables, the mean values (Graph B) have a high value due to their direct relationship with the whole spatial structure. As can be seen in the graphs, there is a definite upward or downward trend in the design process in the jaggedness, revelation, cluster coefficiency, and roundness meangraphs. The specific trends in these graphs show a significant relationship between these variables and spatial quality, indicating that the test performed shows this relationship well. This relationship is established only in the first half of the design for the variable openness and is not clear in the second half.

The minimum and maximum variables are modified in the design path, and these variables are quite significant in some cases. It is worth noting that changes in the environment do not always affect the minimums and maximums. However, this correlation shows the dual importance of these variables. For example, minimum revelation has a completely increasing trend in the design process. This may indicate that designers often modify at least this variable. In other words, designers

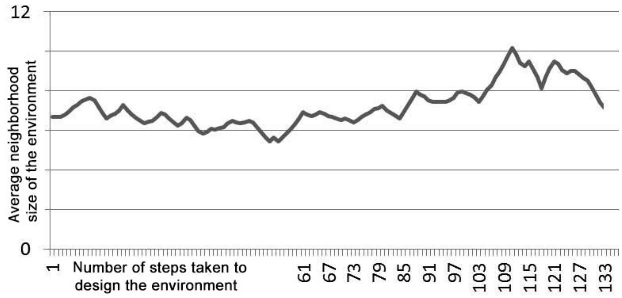

Fig. 5. Changes in the average neighborhood size of the environmental points in the design process of one of the designers.The design of this designer included 133 motions - removing or adding walls. Source: Authors.

consider environments with low values of this variable to be undesirable.

Available studies suggest that increased spatial visibility and expansion are associated with spatial quality. Thus, an attempt was made to define the test so that the changes of other variables are highlighted by restricting the changes of this variable. However, these variables cannot be wholly constrained because of their implication in the environment. As can be seen in Fig. 8, these variables had an upward trend, especially in the first half of the design. Given the well-known relationship between these variables and the quality of the space, it is conceivable that the designers made changes in the first half of the design that increased these variables. However, they encountered limitations in increasing these variables in the continuation of the design due to the spatial structure. Differences in the trend of graphs at different design intervals may also suggest that designers pursued slightly different goals in various phases of design. Given the emergence of meaningful trends, it can be argued that the proposed design methodology can produce appropriate data to understand the relationship between spatial structure and spatial quality. However, the complexity of these trends suggests that even when the only independent variable is spatial structure, the relationship between this variable and spatial quality is complex and varies in different situations. This is in line with what is discussed in the field studies on the relationship between the two variables, indicating the correctness of the proposed methodology.

As noted, one of the goals of the new methodology is to control some variables of spatial structure (spatial dimensions in the present example). The results of the visual analysis indicate that some variables concerning spatial dimensions experience a certain and significant trend during the test. On the other hand, the stability of this process and, consequently, the resulting relationship with spatial quality is not as strong as suggested by the theoretical foundations. So, it can be argued that controlling the variables to improve the effect of other variables was only partially successful.

- Statistical analysis of results

Analyzing the statistical correlation between the design process and the variables is another way to analyze the results.The correlation (Pearson-R) among the variables and the design process (continuous one-unit increase in the designer steps) can be seen in Table 2. According to Table 2, most of the values with high correlation perceived by visual analysis also have high values (i.e.,above +0.5 or less than -0.5) in statistical analysis. Although this analysis has a higher scientific and statistical accuracy, it lacks the intuitive possibility provided by visual analysis.

Each of these values is the average of the five samples under consideration. The values of one variable (jaggedness) for the five selected designers are given in Table 3. It is noteworthy that the correlation is always a number between +1 and -1. The average correlation of five samples can show high values only when:i) the correlation values of the samples are high and ii) the correlation values of the samples are in one direction. Accordingly, if high correlation values are obtained for the mean of a variable, such as the mean jaggedness, the results are statistically very reliable. A p-value validity test can be used to check the validity of the results. The p-value can be easily calculated using the correlation value and the number of samples with calculators available on the Internet. The results of the p-value test for the results are very low and, in most cases, less than one in ten thousand, suggesting that the probability of accidental occurrence of the relationship is very low and that the relationship between the two variables is statistically accepted and established. That is, it can be said with high confidence that as the design

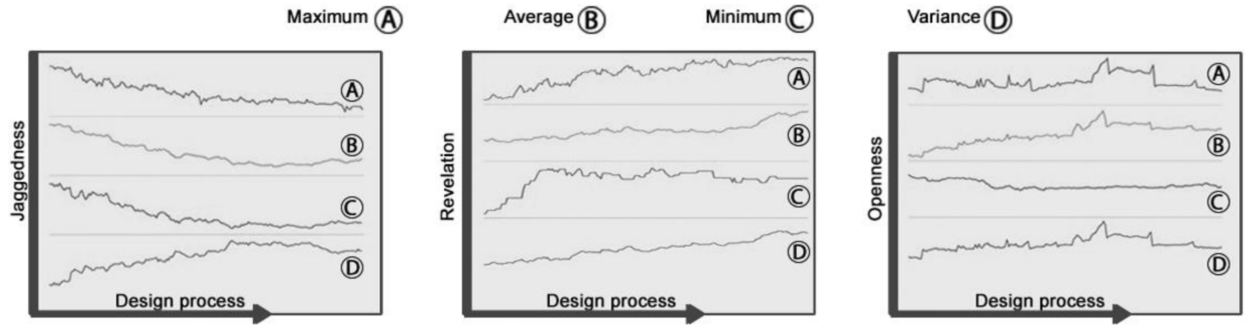

Fig. 6. Graphs of openness and spatial communication. Source: Authors.

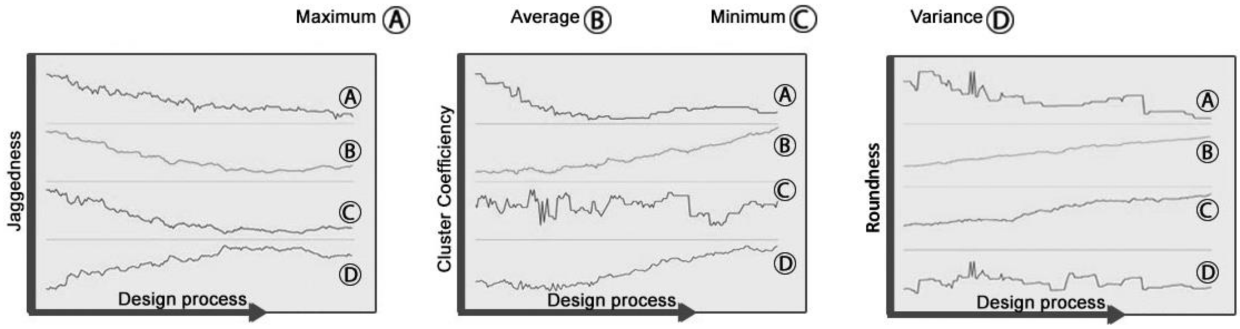

Fig. 7. Graphs of spatial complexity and spatial order. Source: Authors.

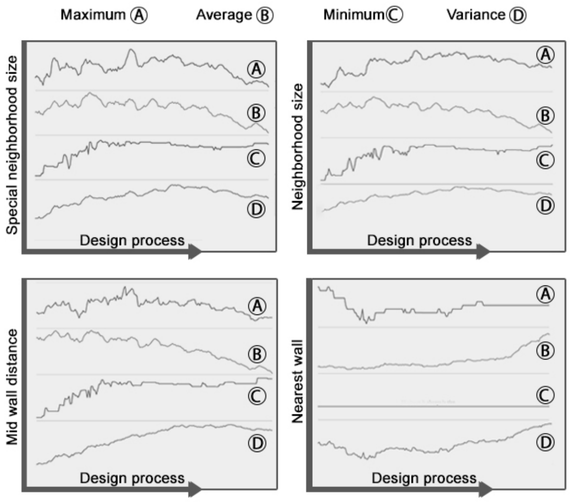

Fig. 8. Graphs of spatial visibility and expansion. Source: Authors.

process of the designers progresses, the jaggedness decreases.

- The validity and reliability of the proposed methodology

After considering the qualitative and quantitative results of the previous two sections as well as the intrinsic characteristics of the methodology, the following issues should be considered regarding the validity of the proposed methodology:

- The proposed methodology measures spatial quality based on the behavior and design of designers. In this way, the accuracy of this measurement depends on the designers' ability. However, spatial quality can even be defined based on the designers' opinion and considered as a basic variable because there is no standard for spatial quality;

- Isovist constraints on the quantification of the spatial structure are also reflected in the proposed methodology and reduce validity. No other powerful and reliable tool for quantifying spatial structure is known at present;

- The test enables successful control of intervening variables, which is desirable. However, great care must be taken to evaluate the spatial quality in the real world based on the results of this study due to the existence of other variables such as light, performance, etc., and the complex interaction of these variables. Accordingly, using the results in the real world reduces the validity of the proposed methodology.

- The following also affects the reliability of the proposed methodology:

- The reliability of the test is reduced due to the limited size of the sample selected from among the study

Table 2. The correlation between variables and the design process (continuous one-unit increase in the designer steps). Highly significant correlations are highlighted. Source: Authors.

Variable	Mean	Maximum	Minimum	Variance
Neighborhood size	0.30	0.45	0.61	0.44
Mid-distance wall	-0.01	0.13	0.68	0.50
Nearest wall	-0.07	-0.27	-	-0.12
Special neighborhood size	0.39	0.61	0.57	0.45
Jaggedness	-0.84	-0.58	-0.67	0.52
Openness	-0.19	0.25	0.56	0.10
Revelation	0.20	0.02	0.03	0.14
Cluster coefficiency	0.01	-0.65	-0.38	-0.22
Roundness	0.85	-0.61	0.75	-0.40

population. As with other methodologies, the proposed methodology proposes comprehensive and organized sampling from among the statistical population (the community of architects) to increase reliability;

- The set of spatial structures that can be used as a test basis is very extensive. So, general quantification of the relationship between the two main variables requires tests in a diverse and wide set of structures;

The robust results of the p-values test indicate the high reliability of the proposed methodology;

- Due to the integration of several designers' designs in the proposed methodology, the split-half method is also applied, which is another sign of the high reliability of the proposed methodology.

- According to the above, the validity of the proposed methodology does not seem to be much higher than previous methodologies.Still, its reliability is significantly higher according to the results of the p-value test and the split-half method.

- **Evaluation of the results in terms of the relationship between spatial quality and spatial Structure**

One of the tests to evaluate the accuracy of the methodology is to check the results. The confidence in the accuracy of the proposed methodology is increased if the results are consistent with the results of previous studies but completer and more accurate. In the following, the relationship between spatial structure and spatial quality is examined based on the obtained results, and Attempts were made to examine the results by assuming the accuracy of the methodology.

- Spatial communication and freedom of motion

Changes in the variables concerning spatial communication and freedom of motion in the design process are shown in Fig. 6. Increasing the mean of the two variables of openness and revelation in the design process suggests increasing spatial communication, opening dead ends, and better access to the environment. Designers seem to expand spatial communications and modify accesses throughout the structure to enhance spatial quality. On the other hand, jaggedness is significantly reduced at the beginning of the design. Highly jagged points indicate spaces with high elongation and low width of the field of view, while the area of the field of view is small. These spaces often occurred at the intersection of several corridors in a multipath manner. The reduction of this variable in the first half of the design indicates the elimination of multipath and can be attributed to the definition of specific paths at intersections. Elimination of multipath along with increasing openness and spatial communication can be done by creating more openings for larger spaces and fewer openings and defining a specific path for smaller spaces.

- Spatial complexity and order

The average increase in cluster coefficiency during the design process (Fig. 7) shows an increase in visual communication and the removal of visual barriers between sub-spaces. On the other hand, the increase in the average roundness values indicates an increase in the jaggedness of spaces. Changes in the two variables indicate that designers have classified the environment

Table 3. The correlation between jaggedness and the design process (continuous one-unit increase in the designer steps) of each sample. The p-value test results for all values except the minimum and the variance of the sample are less than one in ten thousand. Source: Authors.

The sample number	The sample steps	Mean	maximum	Minimum	Variance
1	133	-0.97	-0.82	-0.89	0.80
2	180	-0.93	-0.63	-0.86	0.85
3	96	-0.96	-0.37	-0.79	0.34
4	306	-0.45	-0.31	0.01	-0.17
5	102	-0.89	-0.78	-0.79	0.80
Mean values	163	-0.84	-0.58	-0.67	0.52

into smaller spaces (rooms) with geometric shapes with a low and often jagged perimeter and have removed the visual barriers to these classes. Increasing the values in the graphs of cluster coefficiency and roundness due to their negative relationship with the complexity index on the one hand and decreasing jaggedness due to its positive relationship with the complexity index, on the other hand, indicates a decrease in complexity during the design process.

- Spatial visibility and expansion

The variables of neighborhood size, specific neighborhood size, nearest wall, and mid-wall distance are related to spatial visibility and expansion (Fig. 8). As mentioned in the methodology subsection, the test was attempted to be designed in such a way that the isovist variables changed minimally to emphasize other variables. Since this goal cannot be fully achieved, it seems that in the present test, the relationship between spatial quality and visibility is effective. On the other hand, it provides an opportunity to examine changes in spatial visibility and expansion in the process of increasing the spatial quality by designers through the examination of the graphs of the two variables. When examining the graphs, the first thing to consider is the drastic changes of maxima and minima in the first third of the design, with a rapid increase in the minima and a decrease in the maxima in the graphs and then their fixation. At the same time, the values of the neighborhood size and the specific neighborhood size increase in the first third of the design. These changes could reflect the designers' efforts to eliminate small, humanly enclosed spaces or integrate them at the beginning of the design process. Since the total volume of the environment is probably constant in the first third of the design process, this reduces the maximum space because some of these spaces are added to solve the problem of smaller spaces.

Conclusion

The quantification of the relationship between spatial structure and spatial quality can lead to the development of standards by scientific and legal authorities for spatial structures, the need to implement them will be effective in reducing undesirable architectural examples. On the other hand, this quantification can be used to develop design auxiliary software. By showing potential weaknesses to the designer, these tools can save design time and increase design quality. According to the findings of the proposed methodology, there is a strong correlation between isovist analysis and spatial structure and quality and their ability to express spatial properties. The results show that the isovist analysis and the variables derived from it, at least relatively, serve as a quantitative model for the expression of spatial properties and can reflect some of the properties of spatial structure that affect spatial quality. However, given the intrinsic correlation of many of these variables, it seems that this tool needs to be seriously upgraded to become a powerful tool for interpreting the basic properties of spatial structure into a set of quantitative variables.

The analysisof theresultsfrom another angle indicatesthat during the design process and by increasing spatial quality,visual communication, spatial expansion, and spatial communication increasewhile complexity decreases. So, it can be concluded that in the tested environment, there is a direct relationship between visual communication and spatial expansion and also between spatial communication and spatial quality and that there is an inverse relationship between spatial complexity and spatial quality. In general, the discovery of solid correlations between spatial structure and spatial quality in qualitative and visual tests as well as quantitative and statistical tests shows that the proposed methodology performs well in explaining the relationship between spatial structure and spatial quality. The proposed methodology is also highly reliable and provides entirely meaningful results. The proposed methodology is highly reliable and gives significant results. The result analysis can also be used for qualitative analysis of the relationship between spatial quality and spatial structure in different spatial configurations and provide significant results. Using this tool in a wide range of spatial structures can lead to a more accurate and even quantitative explanation of the relationship between spatial structure and spatial quality.

References list

• Aknar, M. & Atun, R. A. (2017). Predicting movement in architectural space. *Architectural Science Review*, 60(1), 78–95.

• Amini Behbahani, P., Gu, N. & Ostwald, M. (2017). Viraph: exploring the potentials of visibility graphs and their analysis. *Visualization in Engineering*, 5(1).

• Appleton, J. (1975/1996). *The experience of landscape.* London: John Wiley.

• Benedikt, M. L. (1979). To take hold of space: Isovists and isovist fields. *Environment and Planning B: Planning and Design*, 6(1), 47-65.

• Benedikt, M. & Mcelhinney, S. (2019). Isovists and the Metrics of Architectural Space. *Articulating Architecture's Core in the Post-Digital EraAt*, 27-30.

• Berlyne, D.E. (1951). Attention, perception and behaviour theory. *Psychol Rev*, 58(2),137–146.

• Dosen, A. S. & Ostwald, M. J. (2016). Evidence for prospect - refuge theory : a meta - analysis of the findings of environmental preference research. *City*, *Territory and Architecture*, 3, 1–14.

• Esfandiari, A. & Turkashvand, A. (2020). Application of Isovist analysis and sightlines in measuring visual quality of residential complexes (Case Study: Kermanshah City). *Motaleate Shahri*, 9(35), 19-32.

• Franz, G. & Wiener, J. M. (2005). Exploring isovist-based correlates of spatial behavior and experience. In A. van Nes (Ed.), *Proceedings of the 5th International Space Syntax Symposium*. Delft, NL. TU Delft Press.

• Gallagher, W. (2007). *House thinking: A room-by-room look at how we live.* New York: Harper Collins.

• Heydarian, A. Carneiro, J. P. Gerber, D. Becerik-Gerber, B. Hayes, T. & Wood, W. (2015). Immersive virtual environments versus physical built environments: A benchmarking study for building design and user-built environment explorations. *Automation in Construction,* 54, 116–126.

• Hildebrand, G. (1991). *The wright space: pattern and meaning in Frank Lloyd wright's houses*. Seattle: University of Washington Press.

• Hildebrand, G. (1999). *Origins of architectural pleasure*. Berkeley: University of California Press.

• Hwang, J. & Lee, H. (2018). A Parametric Design Model for Numerically Measuring the Design Attributes of Prospect-Refuge. In *Proceedings of the CAADRIA 2018,* Beijing, China, 17–19 May 2018; pp. 577–586.

• Jhangiani, R. S., Chiang, I. A. & Price, P. C. (2015). *Research methods in psychology (2nd Canadian Edition)*. Retrieved from https://opentextbc.ca/researchmethods/. Kaplan R, Kaplan S (1989) The experience of nature: a psychological perspec- tive. Cambridge University Press, Cambridge.

• Kaplan, R. & Kaplan, S. (1989). T*he experience of nature: a psychological perspective.* Cambridge: Cambridge University Press.

• Kellert, S. R. (2012). *Building for life: Designing and understanding the human-nature connection*. Washington, DC, USA: Island press.

• Karimi Moshaver, M., Hosseini Alamdari, A. & Azad Ahmadi, M. (2013). A Comparative Analysis of Sanandaj Urban Area Examples, using Isovist and Visibility Graph Analysis. *Motaleate Shahri*, 4(13), 33 – 42.

• Lippman, P. C. (2010). *Evidence-based design of elementary and secondary schools: A responsive approach to creating learning environments.* London: John Wiley & Sons.

• Ostwald, M. J. & Dawes, M. J. (2019). Isovists: Spatio-Visual Mathematics in Architecture. *Handbook of the Mathematics of the Arts and Sciences*, pp. 1–13.

• Ostwald, M. J., & Dawes, M. J. (2020). The Spatio-Visual Geometry of the Hollyhock House: A Mathematical Analysis of the 'Wright Space'using Isovist Fields. *Nexus Network Journal*, 22(1), 211-228.

• Portman, M. E., Natapov, A. & Fisher-Gewirtzman, D. (2015). To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. Computers. *Environment and Urban Systems*, 54, 376–384.

• Sailer, K. & Psathiti, C. (2017). *A prospect-refuge approach to seat preference: Environmental psychology and spatial layout.* In Proceedings of the 11th International Space Syntax Symposium (Vol. 11, pp. 137-1). Instituto Superior Tecnico, Departamentode Engenharia Civil, Arquitetura e Georrecursos,

Portugal.
• Sanagar Darbani, E. Monsefi Prapri, D. Taherkhani, A. & Hajifathali, S. (2019). Assessing the sense of security and crime prevention in the public spaces of residential complexes by using Prospect, Refuge, and Escape. *Order & Security Research Journal*, 12(2), 1-28.
• Shokohi Dehkordi, K., Hashemnejad, H., Ikhlasi, A. & Saleh Sadeghpour, B. (2013). Sketching Architectural of Process on Effects Sketchup of Evaluation. *Bagh-e Nazar,* 10(25), 29- 38.
• Smith, J. W. (2015). Immersive virtual environment technology to supplement environmental perception, preference and behavior research: A review with applications. *International Journal of Environmental Research and Public Health*, 12(9), 11486–11505.
• Stamps, A. E. (2006). *Literature review of prospect and refuge theory: the first 214 references.* Institute of Environmental Quality, San Francisco, CA. Accessed on the internet on 2010-04-14 at http:// home.comcast.net/~instituteofenvironmentalquality/LitReviewProspectAndRefuge.pdf.
• Stamps, A. E. (2008). Some findings on prospect and refuge theory: I. *Percept Motor Skill*, 106,147–162.
• Turner, A., Doxa, M., O'Sullivan, D. & Penn, A. (2001). From Isovists to Visibility Graphs: a Methodology for the Analysis of Architectural Space. *Environment and Planning, B: Planning and Design*, 28, 103-121.
• Ward, T. (2010). *Quantifying qualitative data.* Luettu, 8, 2012. Retrieved from https://pdfs.semanticscholar.org/97 fe/6104d9f9944c37e7155a079a5eab3f71b298.pdf
• Xiang, L. & Papastefanou, G. (2019). Isovist and Psycho-Physiological Stress at the Pedestrian Level: A Real-Time Measurement Case Study in a High-Density City Luyao Xiang. *Georgios Papastefanou,* 4, 463–471.
• Zhang, S., Kim, J., Shih, S.Y., Koo, C. & Cha, S. H. (2017). Immersive Virtual Environment (IVE) as a Potential Tool for Interior Colour Study in Office Environments. *Proceedings of the 34th International Symposium on Automation and Robotics in Construction* (ISARC), 34, 1-5.

HOW TO CITE THIS ARTICLE

Hosseini Alamdari, A.; Daneshjoo, Kh. & Yeganeh, Y. (2022). Design-Based Methodology in a Specific Virtual Environment to Develop a Relationship between Spatial Quality and Spatial Structure. *Bagh-e Nazar*, 19(110), 21-34.

DOI: 10.22034/BAGH.2022.305973.5009
URL: http://www.bagh-sj.com/article_145714.html?lang=en