sustainability

Article

Mosque Morphological Analysis: The Impact of Indoor Spatial–Volumetric Visibility on Worshipers' Visual Comfort

Lana Abubakr Ali and **Faris Ali Mustafa** *

Department of Architecture, College of Engineering, Salahaddin University–Erbil, Erbil 44002, Iraq; lana.ali@su.edu.krd
* Correspondence: faris.mustafa@su.edu.krd or farisyali@yahoo.com; Tel.: +964-0750-452465986

Abstract: One of the essential needs of humans that is influenced by architectural geometry is visibility in indoor areas. Prayer hall geometry dominates the mosque typology and morphology. The spatial–volumetric shapes of interior prayer halls affect worshipers' visual comfort and spirituality. In this study, a new integrative framework is developed to quantitatively describe various mosque typo-morphologies affecting the visual comfort of worshipers, including spaciousness and consciousness, to obtain prayer hall typo-morphological patterns that may provide higher levels of visual comfort. Spatial and volumetric metrics from various prayer hall vantage points are used in this study. A two-dimensional isovist (VGA) map in depthmapX.10 collects spatial metrics, while the grasshopper script in Rhinoceros-7 collects 3D isovist volumetric metrics. The findings confirm the feasibility of creating a prominent area in barrier-free mosque layout designs centered on a central domed roof form.

Keywords: mosque morphology; visual comfort; visibility; visual field; 2D isovist; 3D isovist; VGA

1. Introduction

One of the primary requirements that buildings must meet is the provision of human comfort in indoor environments, which refers to a sense of physical, perceptual, and psychological ease, frequently described as the absence of hardship. Furthermore, the performance of the indoor environment is governed by its four aspects: thermal comfort, acoustic comfort, visual comfort, and indoor air quality [1]. According to Maslow's hierarchy of needs, comfort is considered one of a person's basic needs and a component of physiological accommodation [2]. Under building physics, comfort is studied in architecture. From this point of view, a built environment must meet a certain standard of visual comfort, just like all other physical needs.

Occupants' perceptions of visual comfort are influenced by formal and spatial characteristics of architectural space, such as length, height, volume, balance, permeability, and angle of view, influencing their feelings of spaciousness and consciousness [3]. Accordingly, space syntax is a collection of methods for analyzing spatial layouts and human activity patterns in structures and cities [4]. In addition, it is a set of theories connecting space and society. Space syntax considers where people are, and how they move, adapt, and perceive their surroundings. Many studies of building environments have found that visibility analysis is an effective tool. It assists in understanding the built environment's spatial and visual relationships [5,6], which control how people move, allow for social interactions, create exciting views, and draw attention to significant surroundings. One of the most crucial methods for examining and defining the features of the built environment concerning spatial determination is typology. Similar to this is morphology, which focuses on how elements of architectural form interact with the study of spatial geometry [7].

Historically, the mosque has been the most significant building in Islamic civilization and continues to be an asset for Islamic organizations. The mosque's primary functions are

check for updates

Citation: Ali, L.A.; Mustafa, F.A. Mosque Morphological Analysis: The Impact of Indoor Spatial–Volumetric Visibility on Worshipers' Visual Comfort. *Sustainability* **2023**, *15*, 10376. https://doi.org/10.3390/su151310376

Academic Editor: Paris Fokaides

Received: 27 May 2023
Revised: 21 June 2023
Accepted: 26 June 2023
Published: 30 June 2023

to serve as a place of private and public worship and a center for religious instruction [8]. Aside from their socio-cultural significance, mosques can be distinguished from other building typologies by their distinct function and intermittent operating schedule dictated by local prayer times. Worshipers gather five times each day and once a week for Friday prayers throughout the year. A mosque's prayer hall (or haram) is an essential building component because it is the principal place of worship [9]. Furthermore, the shape and form of the prayer hall serve as the foundation for determining mosques' patterns and geometrical forms. As a consequence, the visual comfort conditions of the indoor prayer hall influence the user's visual performance and spirituality due to the mosque's geometrical form and indoor spatial—volumetric shape.

Even though many studies have been conducted on the visibility of indoor prayer halls in mosques and their relationships to worshiper experience and spaciousness using syntactic parameters, the notion of analyzing the volumetric visibility of the prayer hall and its effect on worshipers' visual comfort has not yet been discussed. Thus, the current study aims to demonstrate how the different typo-morphological patterns of mosques may affect worshipers' visual comfort by analyzing both the spatial and volumetric visibility of prayer halls. The focuses of this study are firstly on how these parameters can be quantified using 2D and 3D isovists, secondly on the relationship between the spatial and volumetric visibility parameters of the prayer hall with the visual comfort of its worshipers, and thirdly on finding mosque typo-morphologies that may have better visual comfort than others.

2. Literature Review

2.1. Previous Studies on Spatial Visibility Analysis in Architecture

Several alternatives have been provided to deal with the visualization problem in the built environment. Still, many fail to consider the user's visual perception of the environment or classify the various options.

Isovist graphs and graph approaches have been used to represent human perception in buildings and urban areas in space syntax and cognitive science. For example, the authors in [6] used isovists to build a graph of mutual visibility between sites. They employed isovist polyhedron VGA (visibility graph analysis) to show that visibility graph properties are associated with spatial manifestations such as way-finding, movement, and space utilization. Furthermore, isovist and place graphs are used to assess environmental behavioral and affective reactions; they appear to be beneficial in various domains ranging from abstract architecture to behavioral studies to cognitive science studies on mental representations via 2D isovists in space syntax [10]. Notably, the authors in [11] created a wide range of isovist analysis measures, many claiming to provide unique insights into architectural space. They showed how to leverage the isovist view field in a novel approach to assist the manual estimation of global visibility attributes while avoiding the creation of a full visibility graph. Depthmap, on the other hand, has been used to quantitatively study pathways' spatial–visual features through five of Wright's textile block residences. Exceptionally, specific space syntax characteristics and isovist models allow for the definition of space as perceivable by an individual [12] in which the properties of space design and isovist measurements are compared to determine whether the human perception of a simple space is accurate and correlated with isovist indicators within an architectural model. Furthermore, isovist measures are examined, as they reflect the recurrent structures seen in various buildings, and these structures are significant as they represent ideas that are understandable to people [13].

2.2. Previous Studies on Volumetric Visibility Analysis in Architecture

Twenty years after Benedict's work, Batty was able to compute and represent two-dimensional isovist fields and develop statistical metrics that could visualize spatial attributes and reveal their ability to interpret and quantify architectural and urban morphological differences. For instance, efforts were made toward describing and analyzing the visual experience of walking along a certain street. The cognitive alterations were linked to the isovist features, and the isovist perimeter is a measure of the knowledge of spaciousness, compactness, and closure. Batty proposed an entirely novel strategy that was a development of the isovist theory and aimed to connect it with social and visual issues. This was accomplished by incorporating the concept of isovist into the description of the space structure, including it in the theory of space syntax for the analysis of vision schemes, and then proposing a more general visibility graph analysis technique for points seen from multiple locations within the environment [14].

Fisher-Gewirtzman has attempted to investigate the three-dimensional environment in seeking a method to evaluate human sensory perception. Their approaches to 3D isovist analysis include the creation of a Spatial Openness Index (SOI), which assesses the amount of free space expected to be viewed from a specific point of view [15,16]. Again, a 3D analytical tool for the urban environment is offered that allows for continuous analysis directly and continually during the design process and constant revision of the examined models, which is not possible in other ways. This program uses the ray casting method to analyze the vision of the surface from a particular viewpoint and calculate the optimum view of buildings from the streets. This tool was also created with the Rhinoceros Modeling application [17]. To link this to the Gibsonian visual field, where the measure of three-dimensional vision depends on the interaction between the urban and the lines of sight, Fisher-Gewirtzman and other researchers have begun an additional attempt based on LOS (Line Of Sight) measurement for developing a model to seek accurate visual analysis of a complex 3D environment [18]. Furthermore, Golub et al. performed a visibility study using the bounding box. They provide a 3D visibility analysis representation that incorporates objective and subjective computations to reflect the worth of a view and its impact on a viewer's perception [19]. Conversely, the percentage of visibility from a position is the voxel's volume. In this context, Dalton et al. focused on basic 3D isovist methods for calculating analyses and representations of visible interior space from 1996 to 2014 [20]. They combined apparent three-dimensional geometry with psychological conceptions of spaciousness and openness. Ünlü investigated the extension of syntactic and semantic dimensions of visual perception using an experimental case study, which aids in understanding the dynamic nature of volumetric visibility. Their research focuses on four fundamental themes of the study, which are regarded as the essential components in comprehending the perception of spaciousness and openness [21]. These variables are known as isovist parameters, graph parameters, radial data parameters, and volumetric parameters. Krukar et al. discovered that an embodied 3D isovist predicts human perception of space better than a generic volumetric 3D isovist, particularly in spaciousness and complexity [22]. Similarly, Al-Jameel and Al-Moula investigated the suitability of 3D isovist in detecting and predicting the attribute of surprise in architectural settings. They intended to support the possibility of investing in 3D isovist as an instrument for detecting the experience of surprise in Islamic architecture and evaluating it in new designs. The study utilized a technique for creating a parametric system comprising 3D isovist measurement, transferring the generated data to statistical programs to synthesize them, and then assessing the perception of surprise [23].

2.3. Previous Studies on Spatial–Visibility Analysis in Mosques

Visual comfort is crucial to the interior environment, particularly in mosques. Visibility analysis conducted in numerous studies of mosque architecture on its relationship to social and emotional responses is a criterion for establishing an effective relationship between visual comfort and typo-morphological design. Among the most effective social receptive parameters examined in multiple studies were visual integration and visual entropy, calmness and serenity [24–27], individual soul [28], sense of place [29,30], oneness and unity, impressiveness and stimulation [31], psychological perception [8,32,33], and indoor visual comfort [34].

Numerous studies have focused on the physical components and how they improve worshipers' heart vigilance using a descriptive approach. For example, Abbaszadeh and

Zamani examined contemporary mosques in Iran, focusing on the prayer hall and dome, and demonstrated how their mathematical systems provide a strong sense of the sacredness of the space [27]. In addition, the golden ratio method was used to examine the prayer hall's dimensions and shape over time to determine whether the human scale and proportionality were taken into account to attain beauty and serenity in Erbil's historic mosques [26]. Several metrics that affect individual cognition were investigated, including fullness, clarity, regularity, accuracy, consistency of architectural features, proximity, continuity, and simplicity [26,34,35]. Moreover, Metwally analyzed the historical Sultan Hassan Mosque in Cairo using the Gestalt principles of human tranquility and serenity. He pointed out that the physical design characteristics of a mosque include functionality, flexibility, accessibility, safety, comfort, visual-metric integration, controllability, connectivity, occlusion, closeness, visibility, etc. [25].

Due to its many benefits and uses, the space syntax method is one of the most interesting methods for studying, analyzing, evaluating, and measuring. Ismail et al., for instance, evaluated historical mosques in Cairo, Egypt, using user experience surveys and spatial syntactic evaluation to examine places of worship that have long been known to draw worshipers and leave them with a sense of calm and serenity [24]. To determine how "static" space configurations influence people's spatial perception and experience, Tarabieh used space syntax's "Depthmap–X" to examine the mosque design's parts [31]. Moreover, the plan configurations of 14 Mamluk models (1260–1517 AD) were evaluated using VGA to compare spatial and formal characteristics [34]. Similarly, Adli and Chemrouk described a method of interpretation that integrates the syntactic and semantic categories of architectural elements utilizing Depthmap in mosques in Algiers by analyzing syntactic and semantic factors [36].

Thus, the significance of using the space syntax concepts including isovist area, isovist perimeter, occlusivity, and circularity [15] in the perceptual evaluation of the connectivity [37,38], complexity [39,40], and spatial openness [14] of spaces has been highlighted by early researchers. Although these provide an idea of the expansion of space conception, research helps fill the void left by the absence of volumetric space characteristics provided by prior studies, particularly about the interior prayer halls of mosques with their relationship to visual comfort. Although visual comfort is a subjective concept that human sensations and emotions can influence, this study focuses primarily on spatial and volumetric visibility parameters that have been shown in previous studies to help evaluate worshiper visual comfort and compare and contrast the typo-morphological design patterns of various mosques. To achieve this endeavor, the research seeks to find answers to the following questions and inquiries:

1. What are the differences in visual comfort between various mosque typo-morphologies as indicated by 2D isovist assessments of prayer hall spatial characteristics?
2. What are the differences in visual comfort between various mosque typo-morphologies as indicated by 3D isovist assessments of prayer hall volumetric characteristics?
3. Is there a difference in the volumetric visual comfort of worshipers sitting and standing conditions inside the prayer hall?
4. Which Mosque typo-morphology provides the highest level of visual comfort for worshipers by integrating spatial and volumetric vision?

The research concentrates on two main areas of investigation, which are critical measurements in determining visual comfort at every point in the interior spaces of prayer halls:

A. Spatial parameters using 2D isovist.
B. Volumetric parameters using 3D isovist.

3. Theoretical Framework of Visual Comfort

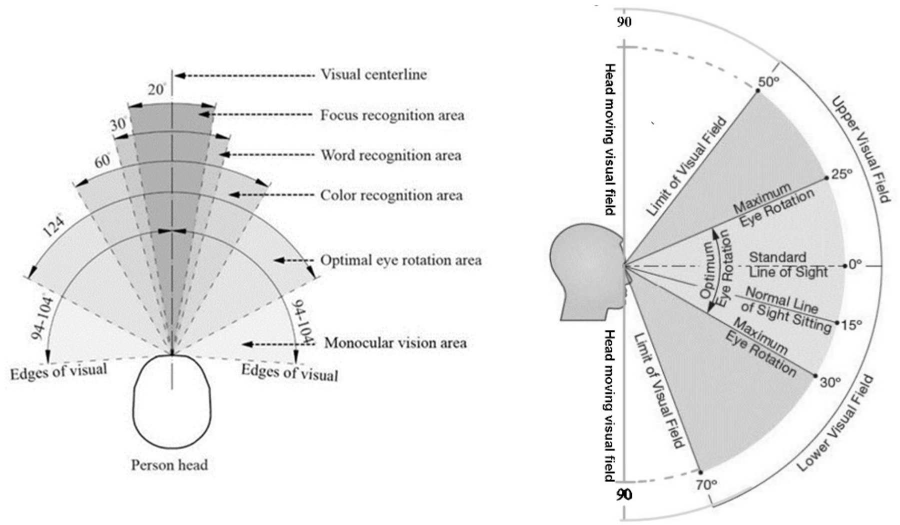
The shape and configuration of spaces affect the visual comfort of humans, as well as their spatial behavior and experiences. Therefore, it is likely that research in the disciplines of architecture and spatial–visual cognition will benefit from description systems that reflect the response of human perception to the significant properties of space. James J. Gibson and his ecological approach came to a new perception approach within this framework. His query, "How can we obtain a constant perception of our environment with constantly changing sensations?", underscores the fact that prior philosophical approaches to the definition and understanding of the phenomenon of perception were ineffective [41]. His information-based process takes into account environmental invariants, from which the sense forwards information regarding valid ecological features. Moreover, Gibson indicates that perception is a function of the individual, and the look at the world at any one time is simply a personal representation of that individual [42]. According to Gibson, perceiving is the active process by which we gain information about the world and stay in interaction with our surroundings. Although the five perceptual systems (ears, nose, eyes, tongue, and skin) all work together to create perception, the visual system (eyes) plays an exceedingly significant part in the information-gathering stage of perception. The observer's requirements influence the amount of information received through the eyes. Furthermore, sensation and perception are two major concepts that deal with visual comfort in architectural space. Perception involves meaning and is affected by light. It is characterized by spatial dimensions, incident variables, surface variables, places, objects, animals, and symbols. Sensations, conversely, are determined by sensitivity and/or the use of the sense organs. They are defined as quality and quantity dimensions such as extensity and intensity, warmth and coldness, tranquility and pleasure, spaciousness and consciousness. As a result, visual perception is not centered on sensations or feelings in space only, instead depending on paying attention to the information in the light [43].

3.1. Visual Field

The visual field is loosely described as the amount of information the human eye can extract from what it is presented. The optical array can be created by actual variations in light in the architectural space, as well as by human movement or by human eye movement. Therefore, a new visual field is produced each time the eyes move to a different stimulation site [42,43].

3.1.1. The Concept of Indoor Spatial and Volumetric Visual Field

The visual field in an indoor architectural space depends on human movement and its angle of sight. To be specific, most people have a horizontal center field of vision that ranges from 50° to 60°. In this position, an object is visible to both eyes at once. Compared to what each eye could see separately, this results in a larger central field [42]. Furthermore, images are clear, depth is perceived, and colors may be distinguished while viewing them within this middle area of vision known as the "binocular field. The monocular vision area can be 90–104° in both the left and right edges of vision. Similarly, horizontal or 0° is the accepted definition of a line of sight for the vertical field of vision. A person's normal line of sight is typically 10 or 15 degrees below the horizontal line. Moreover, the limited visual field is about 120 degrees including 50° above and 70° below the horizontal line. Meanwhile, the overall vertical visual field can reach 1800 with the movement of the head and neck (Figure 1) [44].



(**a**) (**b**)

Figure 1. (**a**) Human horizontal vision angles [44]; (**b**) human vertical vision angles (author adapted from [45]).

3.1.2. Isovist and Visibility Graph Analysis (VGA)

Isovist is one of the key ideas in space syntax, and it describes a visible polygon from a vantage point location in a building environment's layout. An isovist form's boundary is divided into three parts: real surface, occluding radial consistency, and region-boundary surface. The isovist was first defined by [46] as "the set of all points visible from a single vantage point in space concerning an environment". Isovist analysis efficiently examines visibility, in all directions, from a specific observational position or set of positions. Isovist analysis was developed to formally analyze the visibility aspects of a given environment using graph theory, geometry, and mathematics. Turner et al. (2001) created visibility graph analysis (VGA), which allows for the integrative analysis of various positions within an environment by computing the intervisibility of positions that are consistently distributed across the entire environment. This method provides additional second-order metrics including visual stability (e.g., clustering coefficients) and values for global topology-oriented quality (e.g., integration), like the original space syntax method. Another advantage of VGA is that due to its bottom-up approach, the analysis process may be completely automated [6]. Furthermore, the key components for understanding the scope of two-dimensional x–y-based vision are isovist parameters or isometric measurands. As the results of 2D configurations, the area, perimeter, drift, and occlusive provide information on the geometry of space and explain the spatial potentials related to visibility. However, the enclosure of the volume and the shape of the arrangement surrounding the viewpoints are described by the compactness and circularity, which are isovist extracted. Linear and circular, respectively, define a configuration's geometry based on the connectedness or permissiveness of adjacent volumes [21].

3.1.3. Developing Isovist from 2D to 3D Isovist

The set of all points visible from a specific position in space is represented by the objective graphical tool known as isovist, which is used for extensive mapping of surroundings. It also captures the space's perceptually and behaviorally relevant features. Three-dimensional isovist, represented by the z-plane, can be understood through the use of volumetric parameters that are independent of syntactic parameters. The z-plane covers the space between the x and y axes, a gap we call volume, and contributes to concerns about the range of visibility. The third dimension has been a focus of various scholars' research [47,48]. Current research has attempted to identify the broadest range of three-dimensional isovist representations in terms of technique, novelty, and significance (Table 1).

Table 1. Most novel and effective approaches of 3D isovist representation [20].

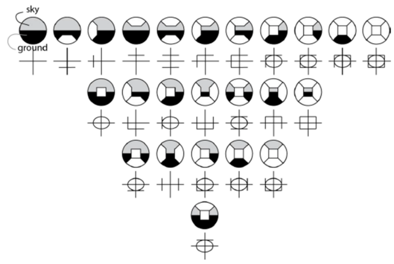
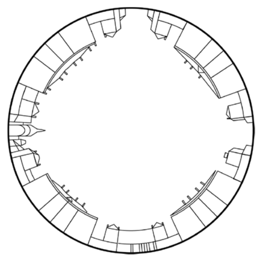
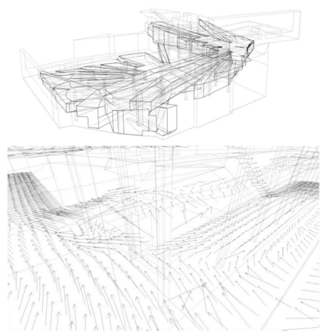
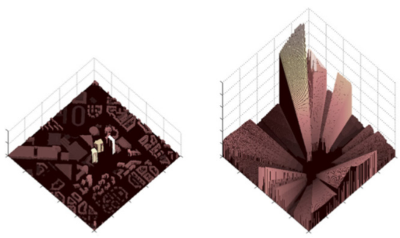
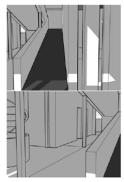
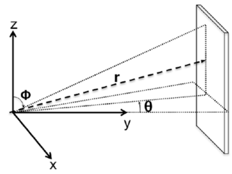
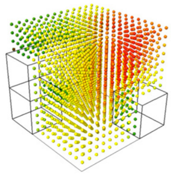
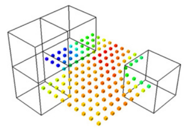
	Techniques-Based Approach	Representation
Penn et al., 1996 [49]	Dalton's IsoCam (at Pangea), 1996, created a variety of "isovist cameras" (IsoCam) that could be installed in any 3D world as part of his project. The 3D IsoCam was one of these, and it generated a representation based on a set of radial lines originating from the point of creation, with the color of the line corresponding to its length.	Not reliable
Thiel, 1997 [50]	The hemispherical projection (HP representation) approximated human vision's 180° horizontal and 135° vertical field of view. The view from one point is represented as a circle with the horizon line operating through its center and any occluding surface. It is called a space-established element position indicator or SEEPI.	
Teller, 2003 [51]	This study created a hemispheric projection image and then used the calculation to generate "sky opening maps" that indicate the proportion of sky visible from a variety of locations.	
Derix et al., 2008 [52]	The study began with the development of a polyhedral volume, a three-dimensional isovist volume containing all visible vertices. Frequently, polyhedral volumes are shown in the form of partially see-through or wireframe 3D solids. Polyhedral field data are a second class of representations; these data fill the scene with a 3D array of points, the size and color of which can be changed to represent attributes like an integration value or volumetric size. 'Force and direction' diagrams show the directionality as a field of floating arrows connecting the isovist's generating point to its geometric centroid.	
Morello, and Ratti, 2009 [47]	This study used DEMs (digital elevation models); they figured out a way to make isovists in three dimensions. The voxels that can be seen from a single vantage point are identified using line-of-sight analysis and displayed as a point cloud in three dimensions. The Isovistmatrix provides a method to generate a three-dimensional array of points, each of which is given a value that indicates its visibility from the ground level.	

Table 1. *Cont.*

	Techniques-Based Approach	Representation
Bhatia, et al., 2012 [53]	Using an extension of traditional ray-casting methods from two dimensions to three, the 3D isovists are built. In this context, "ray casting" means "finding the first object that a ray intersects," which is also sometimes called "ray testing." In this method, the isovist rays extend the complete horizontal view orientation (360 degrees) and the full vertical view orientation (0 degrees to 180 degrees). Each viewpoint's ray projection lengths are measured and added to create an isovist dataset. This projection is repeated at different eye-height increments while the viewpoint remains fixed in the horizontal plane.	 
Varoudis and Psarra, 2014 [54]	They demonstrated a three-dimensional version of Turner's visibility graph analysis (VGA). Two observable values, "3D connectivity" and "3D visual integration," resulted from filling the visible volume with an array of points and constructing a 3D visibility graph, in which edges connect any two independently visible points in a meta-graph representation.	 

As a result, it is possible to conclude the general approaches and techniques for the three-dimensional isovist via Figure 2.

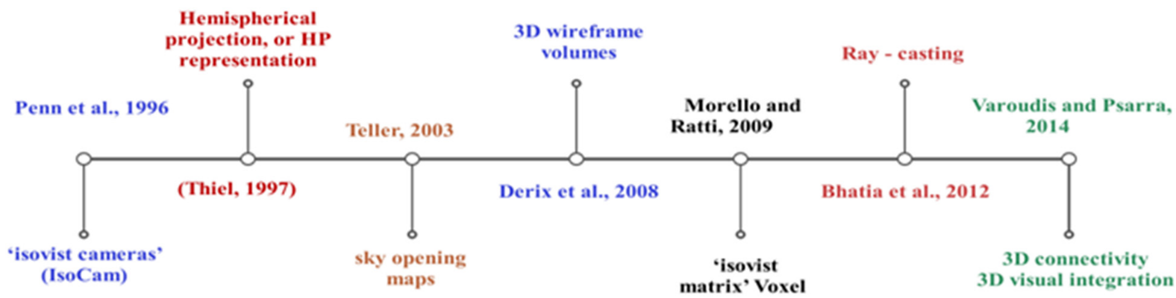


Figure 2. The 3D Isovist representation approaches (authors) [47,49–54].

3.2. Visual Comfort Measures and Their Relationship to the Isovist

As previously indicated, Gibson, 1966, describes the (visual) environment as a surrounding "layout of surfaces" that offers shape to the light scattered from the surface rather than as a collection of objects or as an array of stimuli on which the sensation is imposed. According to him, the perception of the environment is like a sheaf of light rays that are focusing from all angles on a prospective observation point, subsequently referring to the arrangement of rays by intensity and wavelength as the "optic array" [55]. Relatedly, isovists, which are specific to location patterns of visibility, will be used to achieve this, as the isovist is defined as the border that can be seen from a particular point in the context of its environment [46].

3.2.1. Visual Comfort Metrics and Their Relation to Two-Dimensional Isovist Metrics

It would be recommended to increase visual comfort in the perceived area, represented by specific numerical measures of shape and size associated with the isovist field visibility graph analysis. The measurements are divided into five categories as follows:

Spatial Visibility Area

The isovist metric area describes the isovist's surface area and measures the size of a space. In other words, a greater amount of space is visible from the vantage point [13,46,56]. Thus, for every isovist with n vertices with its boundary (*xi, yi*) for each vertex, Depthmap calculates the isovist area (A) using Equation (1) [56]:

$$eA = \frac{1}{2}\sum_{i=0}^{n-1}(xiyi + 1 - xi + 1yi),\ Where\ (xn, yn) = (x0, y0) \tag{1}$$

Spaciousness is one of the primary predictors of human visual comfort in interior architectural spaces. Multiple calculations of the value of spaciousness have led to the conclusion that it is significantly correlated with the isovist area [57,58]. In this vein, [59] discovered in recent their study that perceived spaciousness is associated with spatial isovist area, lighting, and window dimensions. For instance, when spaces are made more compact and symmetrical, people perceive them to be less expansive since they seem both shorter and narrower. In a similar vein, Wise discovered that low values of perimeter and occlusivity and high values of isovist area and radial variance correspond to feelings of expansiveness [60].

Spatial Connectivity

Visual connectivity is a measure of the degree to which one space is visible from its neighbors based on the shortest and longest line of sight [61]. Moreover, connectivity is a measure of the size of the isovist and is determined by how many cells are visible from a given cell. It is referred to as the neighborhood size or degree of the present vertex in graph theory, as shown in Equation (2) [56]:

$$\text{Connectivity} = deg(\mathcal{V}i) = |N(\mathcal{V}i)| \tag{2}$$

where N(vi) is a specific vertex (the neighborhood from which the other cells are visible). The authors of [37] concluded in their study that there is a strong direct relationship between visual connectivity and the visibility of nature that generates a positive mood. Similarly, Yaseen and Mustafa concluded that the connection tool consisted of the parameters of visual connection with nature [38].

Spatial Complexity

It is confirmed that there is a correlation between isovist parameters such as occlusivity, jaggedness or spikiness, entropy, and space complexity, which influence people's calmness and relaxation. The occlusivity defines the length of the isovist that lies in free space. In other words, these are the concealed radial borderlines that can be intended as rays traversing free space after passing an obstruction [13]. A high jaggedness value indicates an isovist with more complicated visual accessibility and more complex space visually [53], which can be calculated according to Equation (3) [53]:

$$\text{jaggedness} \ = \ \text{Isovist Perimeter}^2/\text{isovist Area} \tag{3}$$

There is a positive correlation between entropy, visual complexity, and diversity perceptions [37]. Once again, occlusivity is a mysterious aspect of a space's visual experience that incorporates ambiguity and uncertainty [12,40] It can be calculated according to Equation (4) [16]:

$$O_{\mathcal{V}} = \frac{\sum_{i=1}^{n} O_i}{C_{\mathcal{V}}} \tag{4}$$

Spatial Integration

Hillier and Hanson (1984) proposed approaches to further standardize the mean depth to relieve this problem, creating a new concept known as 'integration' [5]. To calculate the integration, another intermediary measure, 'relative asymmetry' (RA), was determined to provide a standardization of the mean depth to the number of cells in the system to make shallow and deep systems comparable [6]. Additionally, Turner applied these concepts to visual depth in VGA. Thus, visual integration (HI) is derived through multiplication RA as Equation (5) [56]:

$$\text{RA} = \frac{2Dm}{K-2} \tag{5}$$

where DM is the visual mean depth and K is the system cell count. [62] introduced visual entropy (or point depth entropy) to represent a space's global complexity without having to deal with its size. Its value for a VGA cell is Shannon's information entropy applied to any other cell's depth distribution and represented as Equation (6) [56]:

$$\text{Entropy} = Si = \sum_{d=1}^{d_{max}} 1 - p_d \log(P_d) \tag{6}$$

where Pd is the frequency of visual depth d from the vertex and Dmax is the maximum depth from vertex vi. Moreover, when there are multi-different options available, as long as the entire space must be explored, the visual entropy for that space rises. Furthermore, an area with less entropy is better integrated into the overall complex system. Once more, regarding visual integration (*p*-Value), the literature typically considers the integration to be the same as RA, Depthmap inverses the values as Equations (7) and (8) [56]:

$$\text{Visual Integration}[P - Value] = P/RA \tag{7}$$

$$\text{visual Integration } [P - \text{Value}] = \frac{2(\mathcal{K} - \log_2(\mathcal{K}) - 1/(\mathcal{K}-1)(\mathcal{K}-2)}{2\text{D}_{\mathcal{M}}/\mathcal{K} - 2} \tag{8}$$

Thus, the concept of global and local integration involves measuring the integration of parts into a whole. Particularly, high integration was shown to have a better sense of space. Moreover, a high mean depth will result in a poorer perceived area and integration [61].

Spatial Control

It indicates the visual dominance of any given location or where movement may provide access to multiple restricted visual fields [62,63]. Ref. [62] defined visual control as the VGA implementation of the 'control' measure created by Hillier and Hanson (1984) [2]. It is computed by "summing the reciprocals of the neighborhood sizes adjoining the vertex" which can be calculated as Equation (9) [56]:

$$\text{Visual Control} = C\imath = \sum_{\mathcal{V}j\epsilon V(\Gamma \text{i})} 1/K\jmath \tag{9}$$

If the area of a cell can be seen about other immediately visible cells, it is more than one (ci > 1) or less than one (ci < 1). As a result, the central site can be seen in each labeled cell (high control), while not much is seen inside the labeled cells (low control). On the other hand, another isovist attribute given by DepthmapX is a metric named 'Drift' proposed by [62]. The drift magnitude (DrM) is the distance between the observation point, d, and the isovist polygon's "center of gravity", c, where the center of the isovist is estimated as a "polygonal lamina" The amplitude of the isovist drift is determined by the distance between the observation point and the center of gravity in the x and y planes, as well as the square root of the sum of the squares of the planar differences as outlined in Equation (10) [11]:

$$\text{Isovist Drift Magnitude} = \sqrt{(d_{\mathcal{X}} + c_{\mathcal{X}})^2 + (d_{\mathcal{Y}} - c_{\mathcal{Y}})^2} \tag{10}$$

This vector will often point towards the greatest segments of an isovist since these most extended pathways are attracted to the center. Accordingly, it is possible to discover routes towards a minimum path from which the entire world is visible in this manner. In some circumstances, the isovist drift magnitude behaves similarly to the area moments of gravity (point first moment), as its value increases toward the edges away from the center.

Spatial Openness Index—SOI

The Spatial Openness Index is a quantitative measure in terms of visual–spatial information that can be used to evaluate alternative spatial arrangements. It can be calculated by adding Equation (11) into the Depthmap where the occlusivity can be directly calculated through it [16]:

$$\text{SOI} = (\text{Perimeter-Occlusivity})/\text{Occlusivity} \tag{11}$$

This statistic allows for the conscious examination of the transparency and openness of various spatial arrangements and their subsequent rating. Previous studies demonstrated that a higher value of SOI suggests a lower perceived density [16]. As a result, the openness of the space will decrease proportionally to the number of visual obstacles.

Spatial Circularity

Spatial circularity refers to the visible space's roundness, which is argued to increase the contemplative sensation of expansiveness and offer a sense of enclosure. According to Stamps, isovist comparison is easier with the use of the mathematical metrics concavity (Con), sometimes referred to as convex deficit, and circularity (Circ) [37]. In addition, Batty [14] refers to it as convexity, as it originated from efforts to measure roundness. Circularity can be defined as the ratio of the isovist's area to its perimeter. It can be calculated using Equation (12) [11]:

$$Circularity = \frac{Isovist\ Perimeter^2}{(4\pi\ Isovist\ Area)} \tag{12}$$

3.2.2. Three-Dimensional Isovist Metrics and Their Relation to Human Visual Comfort

The current research proposes the most important three-dimensional visibility or volumetric visibility that has a direct relationship with human visual comfort in the internal built environment as follows:

Visible Volume

The amount of visible volume is related to isovist characteristics, where the visual comfort criteria are defined as an isovist area extension. Previous studies with a positive connection to human comfort have considered the nature of the observer's horizontal and vertical vision planes, the radial lines embedded in the volume, and the apparent enclosure's nature [61]. The importance of visible space can be accurately defined using the 3D isovist using Equation (13) [64]:

$$\mathrm{V} = \lim_{\Delta\theta - 0} \sum_{i-0}^{N} \mathrm{Ai} \tag{13}$$

where V is the visible volume; and Ai is the area of a plain of sight, the direction of observer sight divided into N pieces with the interval angle between the radial line of sight ($\Delta\phi = 2\pi/\mathrm{N}$). The maximum value of V is assumed to be the hemispherical visible volume.

Volumetric Openness Index–VOI

The ratio of the visible volume, VV, to the total volume is taken into account, as V divided by Vmax. Equations (14) and (15) [65]:

$$Vmax = \sum_{i-0}^{N} A\ max \tag{14}$$

$$VOI = \frac{VV}{Vmax} \tag{15}$$

where (VOI) is the volumetric openness index, VV is the visible volume, and Vmax is the total volume of the space. Accordingly, the volume index value has been chosen for normalization since the maximum value is 1 and the minimum value is 0. However, values close to 1 are more easily understood by the perceiver [65].

Volumetric Visual Control

Volumetric visual control is also known as the "center of gravity" or "center of vision weight" and refers to the region where the greatest number of radial lines intersect, which is the area that will be visible from the greatest number of vantage points. Moreover, the average intersected radial represents the average view length of all visible space from a given location, which refers to the visual control at a location in visibility graph terminology [5].

Three Dimensional Integration

DepthmapX also provides the metrics (Isovist Min Radial) and (Isovist Max Radial), which are believed to provide a good estimate of space proportionality with human visual relaxation. The 3D isovist volumetric visibility is comprised of the minimum and maximum distances from the generating point to the obstacles. Moreover, the ultimate radial line is essentially the maximum distance in the set of all distances from the generating point to the vertices of the boundary [56]. Similarly, the minimum radial line can be used to determine how near a person is to a boundary, whereas the maximum radial line represents the longest line of sight from that position [66]. Three-dimensional integration can be calculated through mean radial depth or visual mean depth as follows (by authors in Grasshopper):

$$\text{Visual Mean depth} = \frac{(rd)1 + (rd)2 \ldots\ldots + (rd)n}{number\ (rd)} \tag{16}$$

where (rd) is the radial distance from the vantage point to the obstacle, and n is the number of radials in each vantage point.

Volumetric Elongation

It indicates the most substantial radial distance illustrating the longest line from the vantage point to the barrier. Accordingly, the concepts of elongation and compactness are other factors that change the perception of volumetric configuration and the limits of spaciousness. This is similar to Wise [60] saying that perceptual exaggeration of the height of the area causes errors in judgment. On the other hand, Yaseen and Mustafa [38] have important contributions to elongation where the visual distances arise from the surface permeability of space, in other words, the visual perception of adjacent spaces from an opening increases the spatial elongation. Finally, the most significant architectural space visibility measurements for both 2D and 3D concerning human visual comfort are summarized in Figure 3.

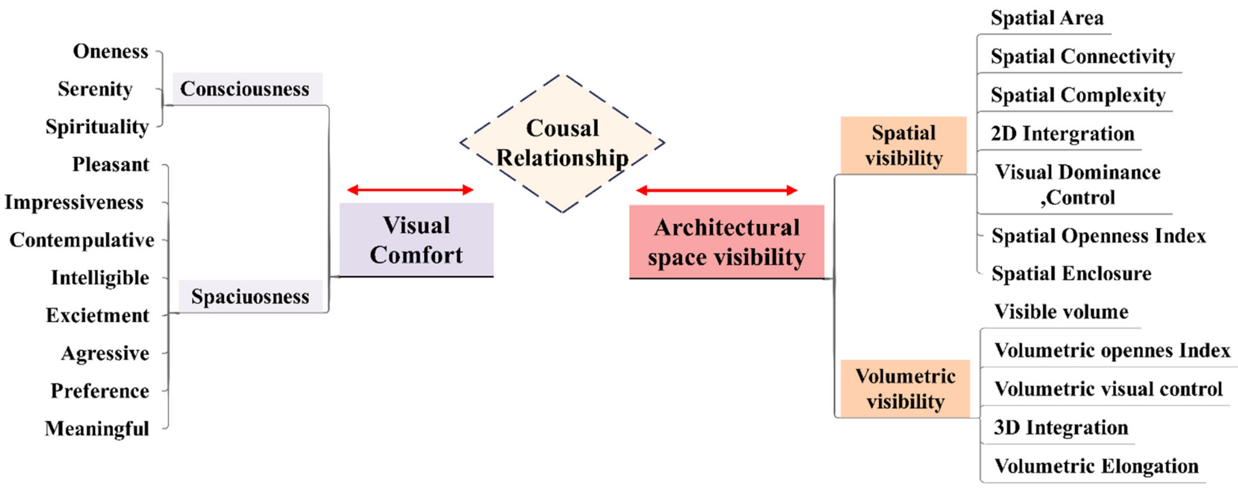


Figure 3. The most effective space visibility metrics concerning human visual comfort metrics (image made by authors).

4. Materials and Methods

4.1. Case Study Selection Strategy

Typo-morphology is the study of the spatial–geometrical characteristics of buildings. In other words, this is the investigation of syntactical and architectural forms. Ali and Mustafa cited multiple studies that discovered a link between mosque design characteristics and visual comfort, as well as their measurements. Interestingly, few of these studies indicated the role that volumetric interior space might play in influencing human perception [67]. A large number of published studies on mosques concentrate on their history and design, with various evaluations of their layout designs using different classifications for multiple reasons (geographical, historical, typological, and morphological). The current study is based on the typo-morphological classification, which combines typological and morphological design characteristics (two-dimensional and three-dimensional) [68]. This led to the investigation of a wide and diverse range of mosque layouts. Moreover, using the categorization and matching system described in the study [68], a variety of mosque syntactic and morphological patterns were selected for analysis, comparison, and classification of the extracted prototypes. As a result, six mosques have been established as main prototypes (see Table 2).

Table 2. Name of selected mosques and classification of their morphological types (by authors).

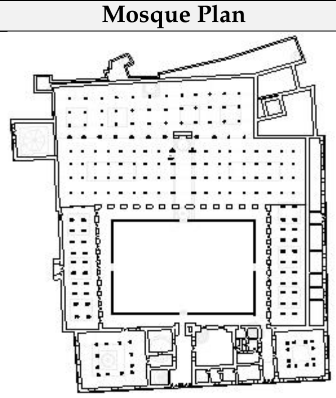
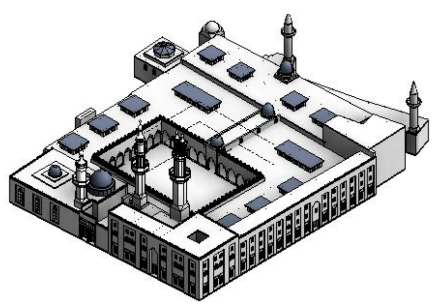
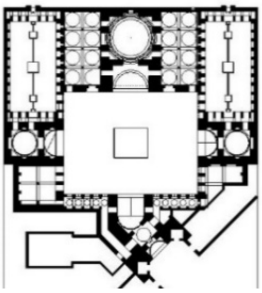
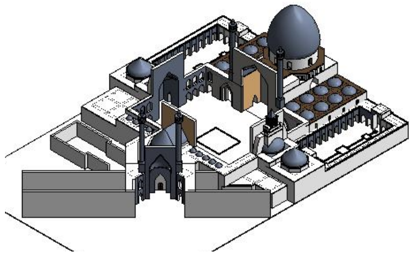
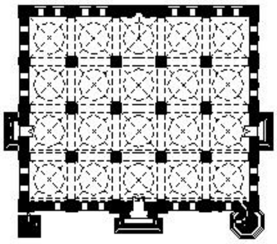
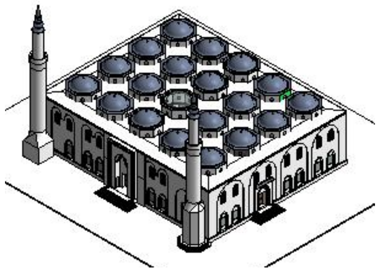
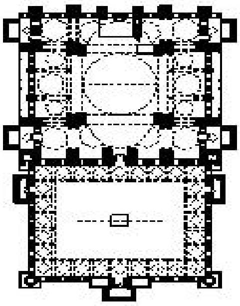
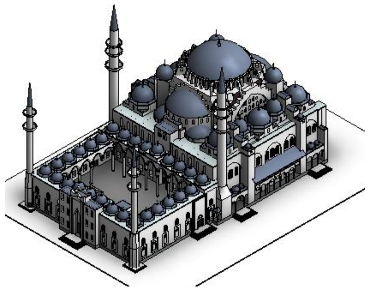
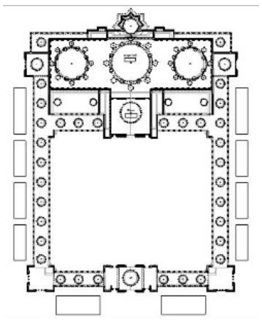
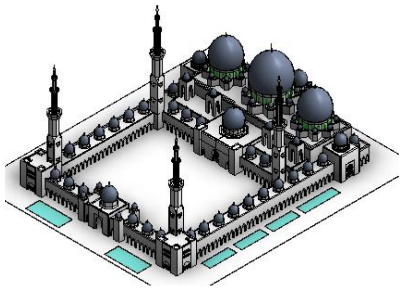
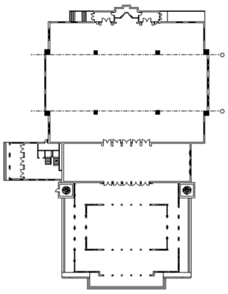
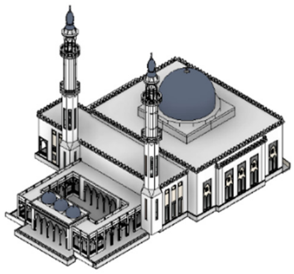
	Mosques Name & Description	Mosque Plan	Mosque Top View
1	Al-Azhar Mosque–Egypt Type 1. E; hypostyle domed articulated courtyard pattern		

Table 2. *Cont.*

Mosques Name & Description		Mosque Plan	Mosque Top View
2	Shah Mosque, Isfahan-Iran Type 2. C; four-Iwan mosque		
3	The Great Mosque of Bursa-Turkey Type 3. A; no courtyard, duplicated mosque pattern		
4	Sulaymaniyah Mosque–Turkey Type 4. B; courtyard supported by central dome pattern		
5	Sheik Zayed Mosque–UAE Type 5. A; massive courtyard, triple dome		
6	Zabeel Mosque, Dubai, UAE Type 6. B; no courtyard, domed square roof		

4.2. Method

There are two primary approaches to the method. Firstly, isovist analysis can be used for two-dimensional space metrics in the depth map (VGA); secondly, Rhinoceros–Grasshopper can be used to generate the 3D isovist. Figure 4 also illustrates a conceptual framework for the research method.

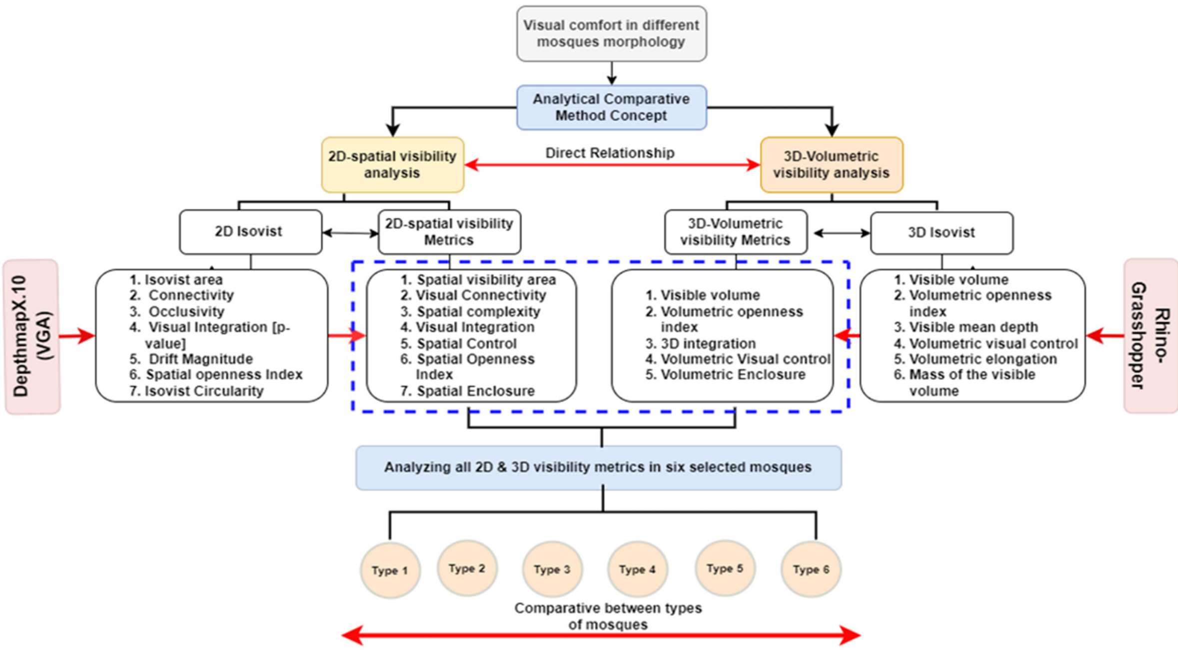


Figure 4. A conceptual framework for the research method (author).

Accordingly, the visual-comfort-related metrics calculated in the current study are clarified as follows:

4.2.1. Two-Dimensional Isovist for Calculating Spatial Visibility Metrics

Visibility analysis measurement was performed using DepthmapX (VGA) version 10. Additionally, the isovist characteristics, such as the area, perimeter, connectivity, occlusivity, Spatial Openness Index, control, and compactness, seem to correlate with visual comfort, including those related to the spatial visibility area, visual connectivity, visual complexity, integration, spatial control, openness, and circularity. As a result, Table 3 illustrates all suggested visual comfort measurements, their relationship to isovist metrics, and how they were calculated both directly and indirectly using DepthmapX-10.

Table 3. Spatial visual comfort metrics with the calculation method for the relevant isovist measures.

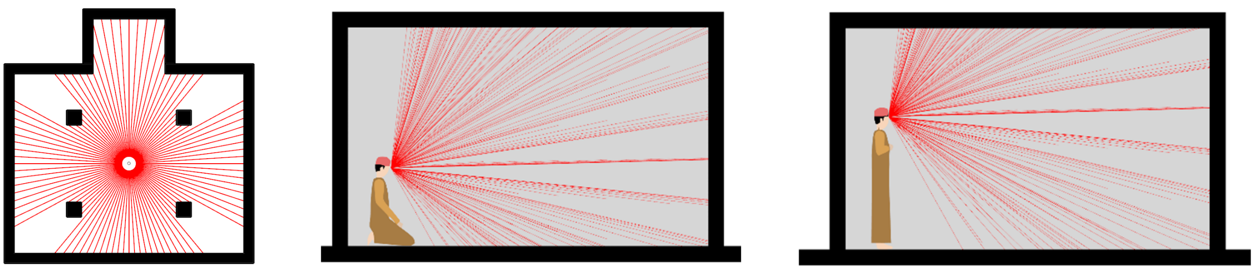
Spatial Design Metrics	Isovist Metrics	Calculation Method	Simulation Program Used
Spatial Visibility Area	Isovist Area	$A = \frac{1}{2}\sum_{i=0}^{n-1}(xiyi + 1 - xi + 1yi)$	Directly into Depthmap.10
Visual Connectivity	Connectivity	$\text{Connectivity} = \deg(\mathcal{V}i) = \lvert N(\mathcal{V}i)\rvert$	Directly into Depthmap.10
Spatial Complexity	Occlusivity	$O_{\mathcal{V}} = \frac{\sum_{i=1}^{n} O_i}{C_{\mathcal{V}}}$	Directly into Depthmap.10
Visual Integration	Visual Integration (*p*-Value)	$\text{Visual Integration } [P - \text{Value}] = \frac{2(\mathcal{K} - \log_2(\mathcal{K}) - 1/(\mathcal{K}-1)(\mathcal{K}-2)}{2D_{\mathcal{M}}/\mathcal{K}-2}$	Directly into Depthmap.10
Spatial Control	Drift Magnitude	$IDM = \sqrt{(d_{\mathcal{X}} + c_{\mathcal{X}})^2 + (d_{\mathcal{Y}} - c_{\mathcal{Y}})^2}$	Directly into Depthmap.10
Spatial Openness Index	Spatial Openness Index	SOI = (Isovist Perimeter-Occlusivity)/Occlusivity	Equation added to Depthmap.10
Spatial Enclosure	Isovist Circularity	$\text{Circularity} = \frac{\text{Isovist perimeter}^2}{(4\pi \text{ Isovist area})}$	Equation added in Depthmap.10

4.2.2. Three-Dimensional Isovist Calculation

The current study introduced a method for creating the 3D isovist utilizing a Grasshopper algorithm in a parametric framework, which was used to calculate the 3D isovists for the selected case studies. Step-by-step 3D modeling has been prepared based on ideas presented in [53], and the features offered by the Grasshopper components from the algorithm itself (component built in Grasshopper) and from the Food 4 Rhino, which provides additional applications to Rhino and Grasshopper. Accordingly, the process was carried out through two main stages as follows:

Stage 1. The 3D isovist was generated using the standard ray-casting method to show what worshipers in standing and sitting height points might see:

(a) Choosing four different vantage points.
(b) Setting the point of view of the worshipers' sitting and standing conditions to 1.00 m and 1.68 m, separately.
(c) Identifying the horizontal direction with an angle (360°) in addition to the vertical direction with angles (0–180°).
(d) The main idea behind creating the 3D isovist is to create a sphere that resembles the visible visual field of a human being, and then use ray-casting technology to measure the length of the rays after they contact the obstacles.
(e) The ray sphere is generated in two steps; the first is to create a semicircle of rays in the vertical direction with a number (180° ray-casting direction) to ensure that the angle between each ray and its neighbor is (10°). The second step is to copy the semicircle in a circular way starting from the point in the horizontal direction with a number (360° ray-casting direction) to ensure that the angle between each semicircle of rays and its neighbors is 10° (Figure 5a–c).
(f) A full sphere of rays emitted from one vantage point is generated using 180 × 360 = 640,000 rays.
(g) The ray discontinues when it encounters an obstacle and is linked to the created ball of rays, making each one an "isovist ray".
(h) When dealing with windows that face outside, the process follows the FLI method [53], which refers to the closing boundaries since they must be specified.
(i) All the above elements have been inputted into the grasshopper script in the Rhinocro.7 plugin with Decoding Space and 3D Convex Hull as shown in Figure 6.



(**a**) (**b**) (**c**)

Figure 5. (**a**) Horizontal 360° direction ray-casting; (**b**) vertical 180° sitting direction ray-casting; (**c**) vertical 180° standing direction ray-casting (authors).

Stage 2. The isovist ray data resulting from the viewpoint include the volume, length, angle, etc. As a result, all metrics have been calculated again by algorithms and equations to identify several volumetric metrics that seem to relate to visual comfort. Moreover, the equations that this study came up with and applied to Grasshopper to discover several volumetric visibility metrics include the visual volume, volumetric openness index, 3D integration, volumetric visual control, volumetric elongation, and the mass of the visible volume, as shown in Figure 7a–e.

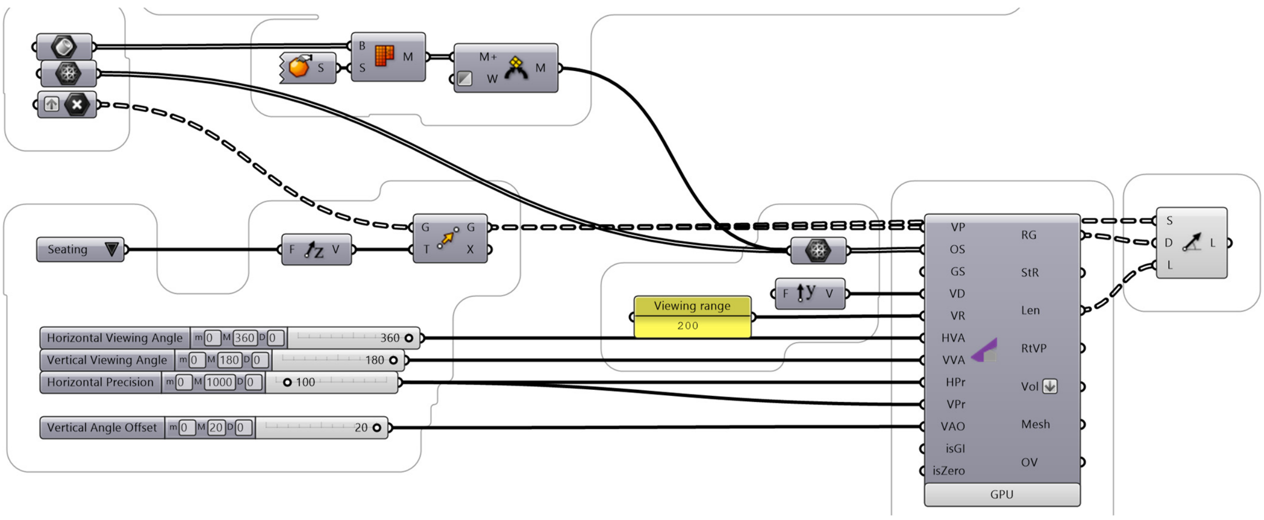


Figure 6. Main Grasshopper script for generation of 3D isovist (author).

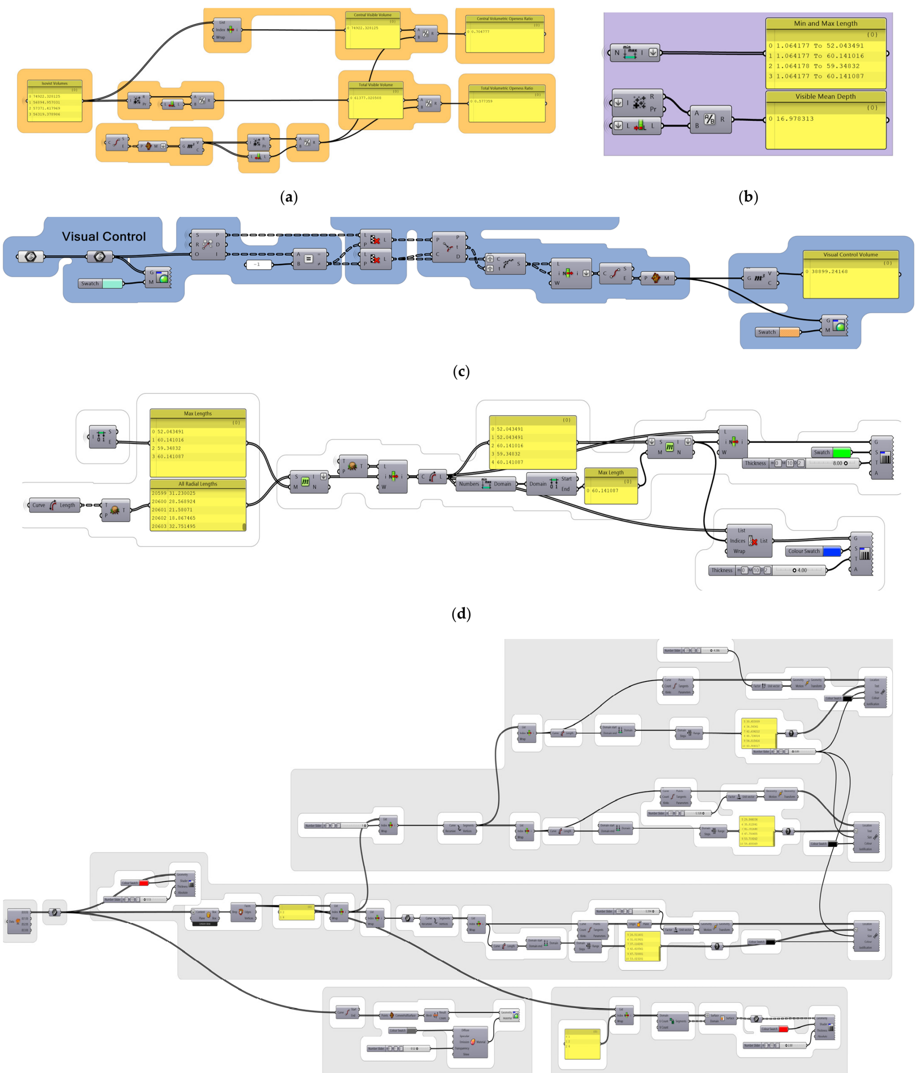


Figure 7. (**a**) Visible volume and visual opening index; (**b**) 3D integration; (**c**) volumetric visual control; (**d**) volumetric elongation; (**e**) the mass of the visible volume.

Then, all algorithm scripts that resulted in the main algorithm were converted via Grasshopper into an Excel sheet and mesh drawing to show the results.

5. Results and Discussion

5.1. Two-Dimensional Isovist Results and Discussion

Using DepthmapX.10, the results of the 2D isovist analysis in graphing different mosque typo-morphologies are presented in Table 4. For most Visual Graph Analysis (VGA) parameters, doors were closed and windows were opened. The reddish color means the highest value, and the blue color refers to the lowest value.

Table 4. Mosque visibility graph analysis using 2D VGA (DepthmapX.10).

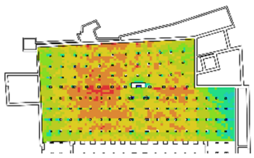
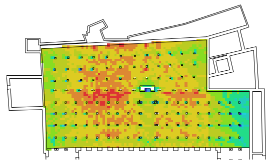
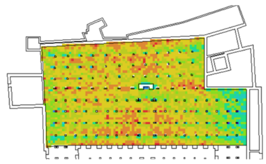
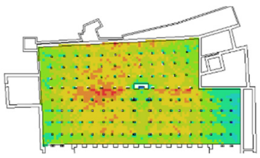
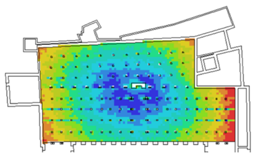
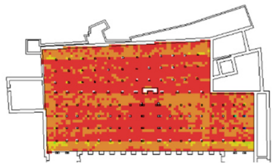
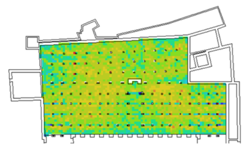
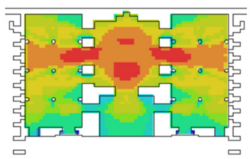
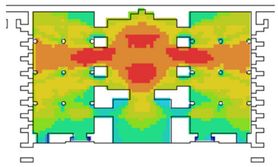
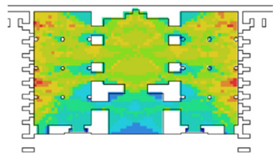
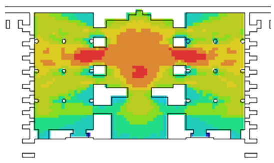
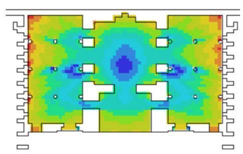
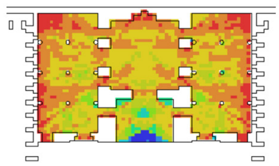
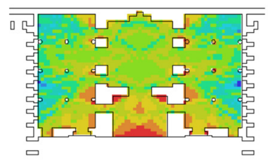
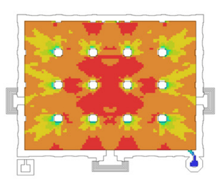
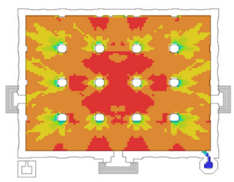
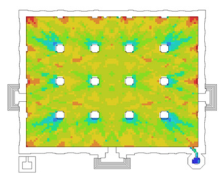
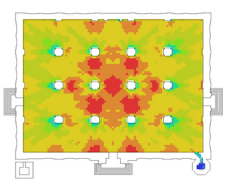
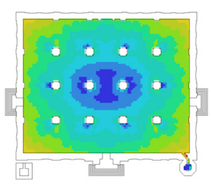
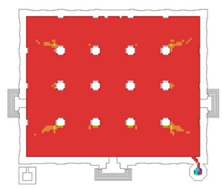
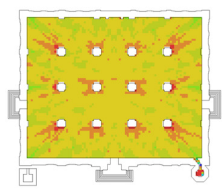
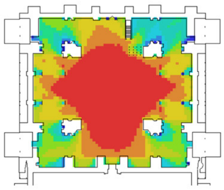
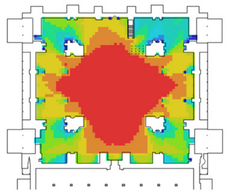
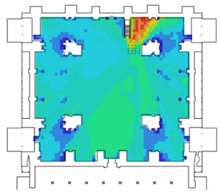
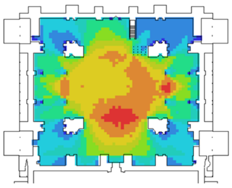
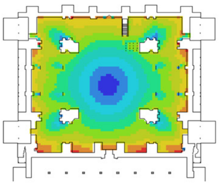
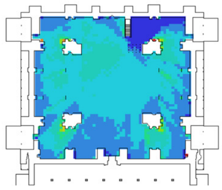
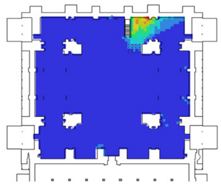
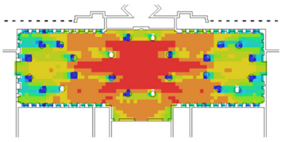
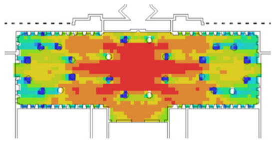
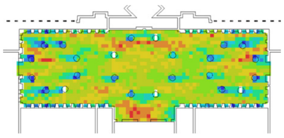
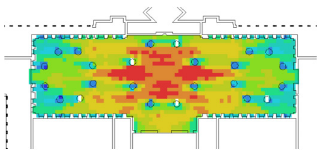
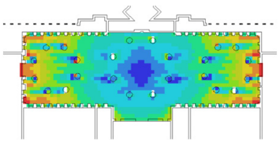
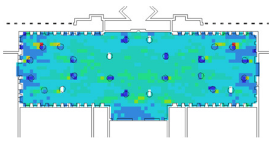
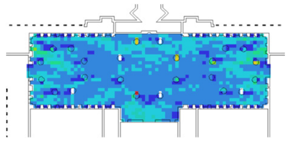
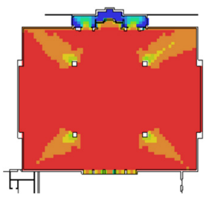
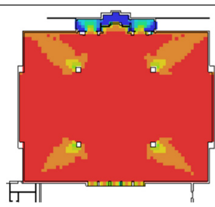
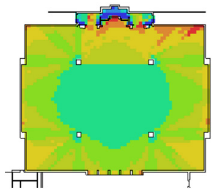
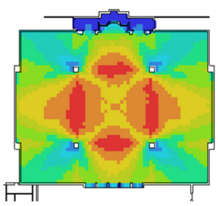
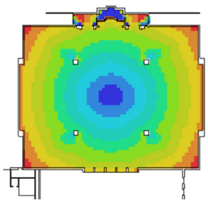
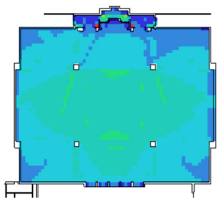
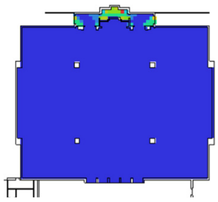
	Name of Mosque	**Isovist Area**	**Connectivity**	**Occlusivity**
	Visual Integration (p-Value)	**Drift Magnitude**	**Spatial Openness Index**	**Isovist Circularity**
Type .1E	Al-Azhar Mosque, Egypt			
				
Type 2. C	Shah Mosque, Isfahan, Iran			
				
Type 3. A	The Great Mosque of Bursa, Turkey			
				

Table 4. *Cont.*

	Name of Mosque	Isovist Area	Connectivity	Occlusivity
	Visual Integration (*p*-Value)	**Drift Magnitude**	**Spatial Openness Index**	**Isovist Circularity**
Type 4-D	Süleymaniye Mosque			
				
Type 5. A	Sheik Zayed Mosque, UAE			
				
Type 6. B	Zabeel Mosque, UAE			
				

Regarding the first question of the current research (what are the differences in visual comfort between various mosque typo-morphologies as indicated by 2D isovist assessments of prayer hall spatial characteristics?), a Kruskal–Wallis test was used to determine the difference between the six mosques' means regarding the following metrics: isovist area (IA), connectivity (Con.), occlusivity (Oc), visual integration (*p*-value) (VI), drift magnitude (DM), Spatial Openness Index (SOI), and isovist circularity (IC) (see Table 5).

Table 5. Metric values for isovist parameters.

Mosques	IA		Con.		Oc		VI		DM		SOI		IC		P
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	
Type.1E	1083.5	459.4	1073.8	462.9	1217.7	591.7	1.5	0.3	14.0	11.4	0.10	0.2	0.1	0.0	$p < 0.001$
Type.2C	889.4	437.6	884.2	433.3	217.3	127.1	1.6	0.6	13.1	9.0	0.59	0.5	10.4	7.3	
Type.3A	1637.1	654.3	3341.4	1336.5	324.7	169.4	2.2	0.6	16.0	13.8	0.55	0.4	11.9	13.7	
Type.4D	1679.3	757.7	1695.6	771.7	475.5	481.0	2.8	1.4	19.1	12.2	0.49	0.5	22.5	95.1	
Type.5A	2762.3	1290.4	690.1	310.5	886.4	472.2	1.9	88.6	26.2	20.5	0.24	0.2	27.2	52.3	
Type.6B	1622.5	219.1	1620.1	2441.0	161.0	44.2	8.1	6.9	16.1	7.9	1.0	0.4	5.2	2.3	

In detail, the results obtained were as follows:

5.1.1. Spatial Visibility Area

Spaciousness is one of the most critical factors in predicting human visual comfort in interior architectural space. There is a correlation between perceived spaciousness and the isovist spatial area. It was discovered that high isovist area values increase the perception of space. In the isovist area, the Sheik Zayed Mosque received a very high value (2762.3), while the Süleymaniye Mosque ranked second (1679.3) (Table 5). In contrast, Shah Mosque has a lower weight (889.4). Accordingly, Sheik Zayed Mosque, with a triple-domed prayer hall typology, appears to have a higher perceived area, which results in greater visual comfort than other prayer halls (Figure 8a).

5.1.2. Spatial Connectivity

Spatial connectedness measures how well one space is connected to another. Furthermore, connectivity is a measure of the isovist size determined by how many cells are visible from a given cell. Bursa Mosque has the highest connection (3341.4) inside the prayer hall, whereas the Great Mosque of Süleymaniye comes second (1695.6). The value gradually decreased (1620.1) for Zabeel and was 1073.8 for Al–Azhar Mosque, and both Shah Mosque and Sheik Zayed Mosque dropped in value with 884.2 and 690.1 due to obstacles inside the hall. See Table 5 and Figure 8b.

5.1.3. Spatial Complexity

It has been proven that isovist factors such as occlusivity, jaggedness or spikiness, and entropy correlate with space complexity; nevertheless, when these parameters are high, it indicates that the space is more complex, which hurts people's ability to relax and feel relieved. Table 5 shows that Al-Azhar Mosque, which has the most complex prayer hall design, achieved the highest occlusivity value of 1217.7. As for the rest of the other mosques, the value decreases to 886.4 for Sheikh Zayed Mosque, 475.5 for Süleymaniye Mosque, 324.7 for Bursa Mosque, 217.3 for Shah Mosque, and finally, 161.0 for Zabeel Mosque, due to their clear layout designs with little complexity Figure 8c.

5.1.4. Spatial Integration

The integration of parts into a whole is what is being measured by the "global and local integration" concept. Greater integration has been linked to a greater sense of place. Table 5 shows that Zabeel Mosque, with a value of 8.1, and Al-Azhar Mosque, with a value of 1.5, have the highest and lowest integration values. Gradually, the level of visual integration also decreases from Süleymaniye Mosque (2.8) to Bursa Mosque (2.2), Sheik Zayed Mosque (1.9), and Shah Mosque (1.6). As a result, hypostyle-type mosques, which typically have columns, do not have a visual connection that is generally recognized in Figure 8d.

Figure 8. (**a**) Isovist area, (**b**) connectivity, (**c**) occlusivity, (**d**) visual integration (*p*-value), (**e**) drift magnitude, (**f**) Spatial Openness Index, (**g**) isovist circularity.

5.1.5. Spatial Control

Spatial Control mainly indicates that a space visible from the most points is regarded as high control. In contrast, when the space is not much seen from other points, it is recognized as a low-control isovist, like the point-first moment of gravity, as the drift magnitude value increases as one moves away from the center. However, when the drift magnitude value rises, the cell begins to move out of view, giving the impression that it is smaller than it is. According to Table 5, Shah Mosque has the best spatial control because most of its cells are located close to the center of the structure. Al-Azhar Mosque, with a score of 14.0, is an example of the second type of mosque, which maintains excellent spatial control over every point of interest. In contrast, Sheikh Zayed Mosque (26.2) has poor spatial control, as shown in Figure 8e, due to the linear rectangular shape of the prayer hall, which means that some locations are far from the center of gravity, and one feels lost as a result of its large area.

5.1.6. Spatial Openness Index

It is possible to compare different layouts with the help of visual–spatial data. The SOI is a metric for measuring how much space can be visible. Consequently, a higher SOI value indicates high perceived space and good emotion. Therefore, Zabeel Mosque has a high value (1.00), reflecting positively on one's feelings. In addition, the values 0.59, 0.55, 0.49, and 0.24 indicate that the openness of Shah Mosque, Bursa Mosque, Süleymaniye Mosque, and Sheikh Zayed Mosque are all good. On the other hand, worshipers' visual comfort is negatively impacted by hypostyle-type mosques such as Al-Azhar Mosque, which has the lowest openness value (0.1).

5.1.7. Spatial Circularity and Enclosure

Spatial circularity and enclosure refer to a circular field of view that helps one feel more spaciousness during meditation and calm. However, as the value increases, so does the feeling of isolation. The excellent roundness may be due to the design of the prayer hall plans in Sheikh Zayed Mosque, with a circularity value of 27.2, and Sulaymaniyah Mosque, with a circularity value of 22.5; it seems that both mosques have a central point and fewer obstacles. In contrast, Al-Azhar Mosque has a low value (0.1) due to its grid layout. See Table 5 and Figure 8g.

5.2. Three-Dimensional Isovist Results and Discussion

The results of the 3D isovist analysis of volumetric visibility metrics of prayer halls for various mosque typo-morphologies resulting from the Rhinoceros version 7 plugin Grasshopper are presented in the form of graphics in Table 6, in addition to data for the values for most of the measures in Table 7.

Table 6. Volumetric visibility analysis drawings (3D isovist—Grasshopper).

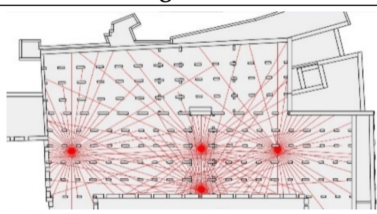
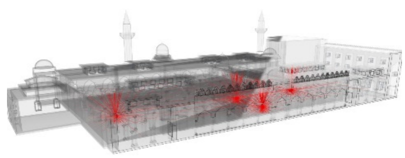
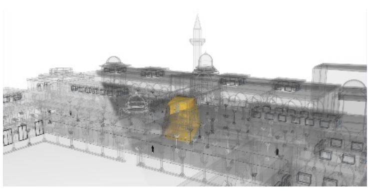
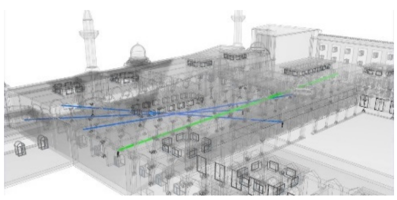
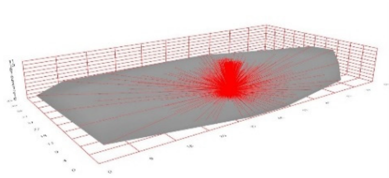
	Mosque Name and Description	Mosque Plan with Selected Vantage Points	Visibility Volume in Standing Vantage Points
	Visual Controllability	**Visibility Elongation in Standing Vantage Points**	**Visibility Mass in Central Vantage Point**
Type .1E	Al-Azhar Mosque, Egypt		
			

Table 6. *Cont.*

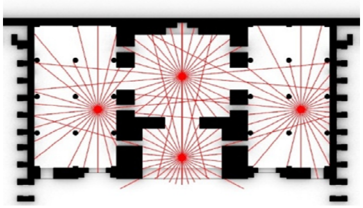
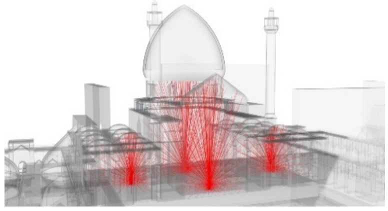
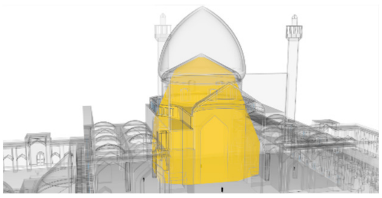
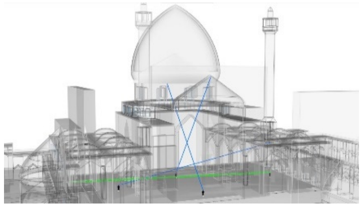
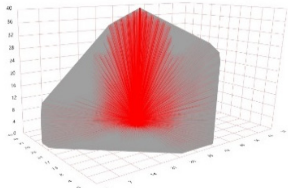
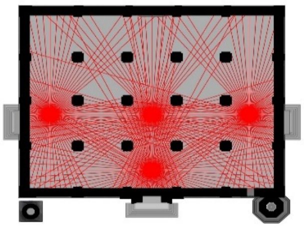
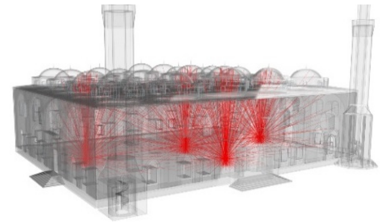
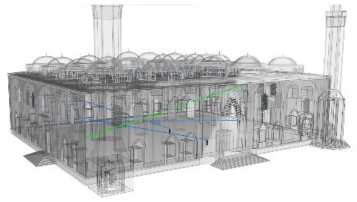
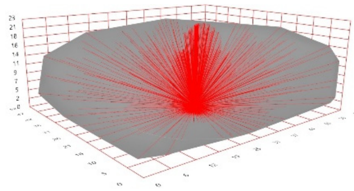
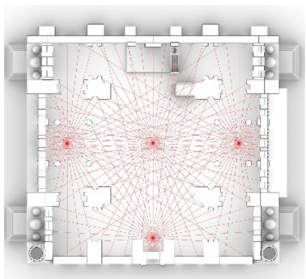
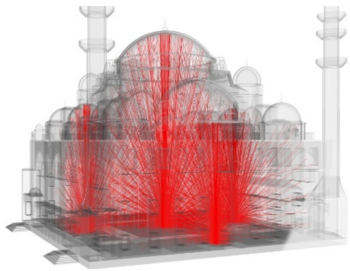
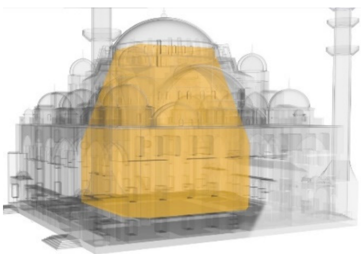
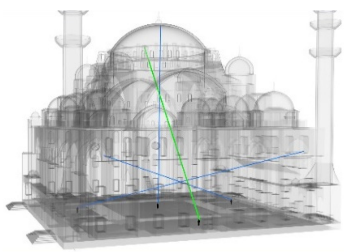
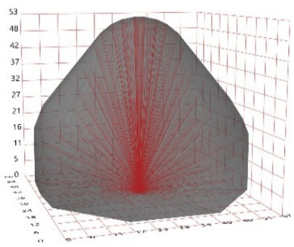
	Mosque Name and Description	**Mosque Plan with Selected Vantage Points**	**Visibility Volume in Standing Vantage Points**
	Visual Controllability	**Visibility Elongation in Standing Vantage Points**	**Visibility Mass in Central Vantage Point**
Type 2. C	Shah Mosque, Isfahan, Iran		
			
Type 3. A	The Great Mosque of Bursa, Turkey		
			
Type 4-D	Süleymaniye Mosque, Istanbul, Turkey		
			

Table 6. *Cont.*

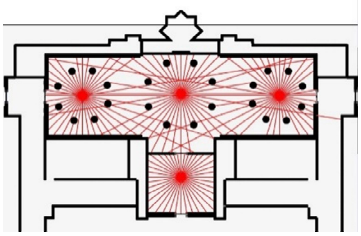
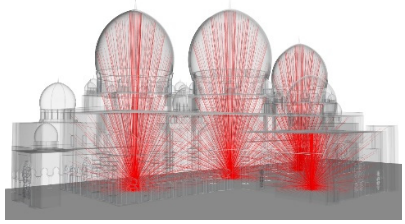
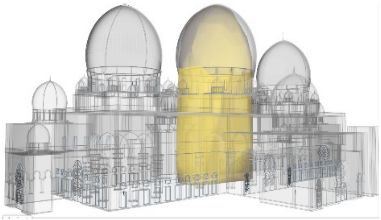
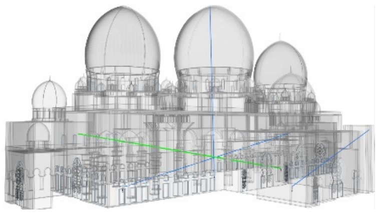
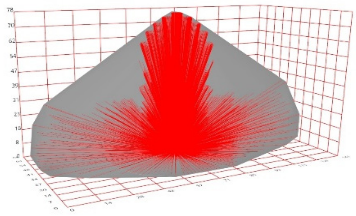
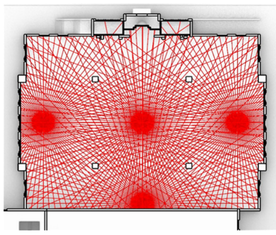
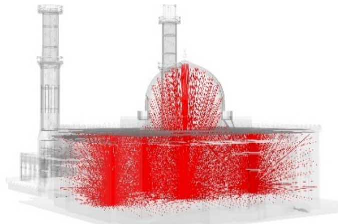
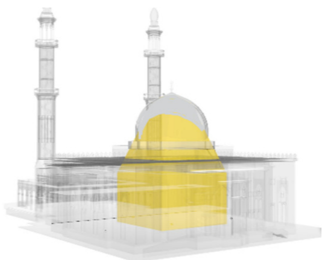
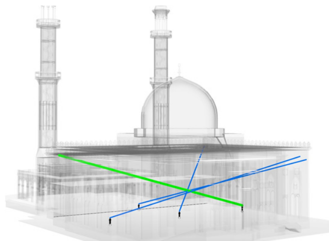
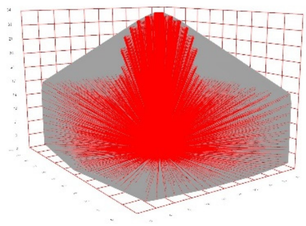
	Mosque Name and Description	Mosque Plan with Selected Vantage Points	Visibility Volume in Standing Vantage Points
	Visual Controllability	**Visibility Elongation in Standing Vantage Points**	**Visibility Mass in Central Vantage Point**
Type 5. A	Sheik Zayed Mosque, UAE		
			
Type 6. B	Zabeel Mosque, Erbil, Iraq		
			

Table 7. Volumetric visibility analysis data value (3D isovist—Grasshopper).

Mosques	C.VV		T.VV		C.VOI		T.VOI		VMD		VVC		VE		P
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	
Type.1E	8789.55	196.65	8528.75	56.21	0.28	0.00	0.26	0.01	7.24	0.35	405.75	0.21	80.10	0.00	$p < 0.001$
Type.2C	30,026.40	207.32	18,126.81	198.34	0.77	0.01	0.46	0.00	12.62	0.30	19,376.6	448.2	61.80	0.00	
Type.3A	28,908.15	346.41	25,178.52	49.36	0.51	0.01	0.45	0.01	12.58	0.22	3677.60	53.74	60.40	0.00	
Type.4D	70,317.45	616.95	56,153.66	170.41	0.72	0.01	0.57	0.00	17.01	0.10	40,872.9	2652	59.10	0.28	
Type.5A	173,318.90	1075.51	106,719.40	364.58	0.82	0.01	0.51	0.01	23.92	0.16	57,825.0	778.4	123.1	0.28	
Type.6B	33,417.0468755	28.92	29,617.02	165.96	0.81	0.01	0.72	0.00	12.88	0.23	9455.5	42.71	48.81	0.00	

Concerning the second question of the current research (what are the differences in visual comfort between various mosque typo-morphologies as indicated by 3D isovist assessments of prayer hall volumetric characteristics?), a Kruskal–Wallis test has been used to determine the difference between the six mosques' means regarding the following metrics: space visible volume in both central vantage point (CVP), total vantage point (TVP), visibility openness index in both single vantage point (C.VOI), total vantage points (T.VOI), visual mean depth (VMD), volumetric visual control (VVC), and visual elongation (VE).

5.2.1. Space Visible Volume

As mentioned previously, visible volume refers to the volume perceived by worshipers in a single vantage point inside the prayer hall. As shown in Table 7, there is a difference in the means of mosques, as indicated by the significant *p*-value (0.000), which is less than 0.05. Sheikh Zayed Mosque achieved the most considerable mean value (173,318.9). This value decreased to 70,317.45 in Süleymaniye Mosque, 33,417.0 in Zabeel Mosque, 30,026.40 in Shah Mosque, 28,908.15 in Bursa Mosque, and 8789.55 in Al-Azhar Mosque, which represents the minimum visible volume among all the six mosques. The visible volume for the total vantage points inside the prayer hall has also been computed. In a similar approach, the differences between the means concerning the six mosques are shown in Table 7. Furthermore, there are differences in the means of mosques in visible volume for the average of total vantage points. The highest mean (106,719.4) was recorded at Sheik Zayd Mosque. As shown in Figure 9b, this value decreases from 56,153.66 in Süleymaniye Mosque to 18,126.81 in Shah Mosque, 25,178.52 in Bursa Mosque, 29,617.02 in Zabeel, and finally, 8528.75 in Al-Azhar Mosque, which represents the minimal visible volume among the six mosques. In short, Sheik Zayd Mosque has a great value for visibility volume at the central vantage point and a total average of four vantage points inside the prayer hall, which indicates that the triple dome and huge area contribute to achieving the most significant visible volume and thus a better sense.

5.2.2. Volumetric Openness Index

As mentioned earlier, the ratio of the visible volume to total volume refers to the openness index; its value ranges from 0 to 1. However, a value close to 1 will have more visibility openness. There is a difference in the mosque's visibility openness based on the significant *p*-value (0.000) in Table 8, which is less than 0.05. Sheikh Zayed Mosque and Zabeel Mosque achieved the best single-vantage-point values for their prayer halls, 0.82 and 0.81, respectively. As for the other mosques, the values ranged from 0.77 in the Shah Mosque to 0.72 in the Süleymaniye Mosque, 0.51 in the Great Mosque in Bursa, and 0.28 in Al-Azhar Mosque. This indicates that the visibility is high in the middle of both Zabeel Mosque and Sheik Zayed Mosque due to their form, shape proportions, and a higher dome in the middle. On the other hand, Süleymaniye Mosque and Shah Mosque also achieved increased visibility in the center due to their vast and central domes. Accordingly, the visibility openness index (VOI) for the total points inside the prayer hall will vary. Table 7 shows that the Zabeel Mosque recorded the most significant value (0.72), and Süleymaniye Mosque ranked second with a high visible openness (0.57). This indicates that the prayer hall visibility openness has a great relationship with the plan layout, but the close-square prayer hall plans with fewer columns achieve better visibility. Mosques with rectangular shapes, such as Al-Azhar, have a lower visibility (0.26) due to many barriers inside its prayer hall and flat roof with low height, as shown in Figure 9c,d.

5.2.3. Volumetric Visual Control (VVC)

As previously stated, the center of gravity or center of vision weight refers to the region where most radial lines intersect and are visible from most vantage points. Although the visibility mass is large, worshipers perceive a greater volume, and the space looks clearer and purer. Based on the data presented in Table 7, Sheik Zayed Mosque has a significant value (48,825) of VVC. Also, Süleymaniye Mosque scored second in the visibility control value (40,872.9), and both mosques have a large high dome in the center of the prayer hall that gives a longitudinal volumetric proportion compared to others. In contrast, Al-Azhar Mosque has a minor mean average for the visual control zone with a score of 405.75. Figure 9e illustrates that visual volume control varies with the mosque typo-morphology. Mosque morphologies with a high value for three-dimensional height concerning their two-dimensional plan layout of prayer halls create a more controlled visible volume of space. Consequently, it is crucial to estimate greater volume to improve visual comfort.

Figure 9. (**a**) Visible volume in a center point for a single vantage point; (**b**) visible volume for the average of multiple vantage points; (**c**) visibility openness index in a single vantage point; (**d**) visibility openness index in multiple vantage points; (**e**) mosque visual mean depth; (**f**) volumetric visual control (VVC); (**g**) volumetric elongation.

Table 8. Comparative study of seating and standing situations from a vantage point.

Hight		N	Mean	Std. Deviation	p
Central vantage point visible volume	1	6	53,234.57	62,565.57	$p > 0.05$ (n.s) *
	1.68	6	53,542.50	63,218.88	
Central vantage point visibility openness ratio	1	6	0.65	0.21	$p > 0.05$ (n.s) *
	1.68	6	0.65	0.22	
Total vantage point visible volume	1	6	37,108.93	38,317.06	$p > 0.05$ (n.s) *
	1.68	6	37,124.28	38,479.35	
Visibility openness ratio	1	6	0.51	0.17	$p > 0.05$ (n.s) *
	1.68	6	0.50	0.17	
Visual controllability volume	1	6	20,745.02	23,404.99	$p > 0.05$ (n.s) *
	1.68	6	21,294.97	23,682.21	
Visible mean depth	1	6	13.44	6.09	$p > 0.05$ (n.s) *
	1.68	6	13.76	6.21	
Volumetric elongation	1	6	69.43	30.48	$p > 0.05$ (n.s) *
	1.68	6	69.30	30.61	

* (n.s): not significant.

5.2.4. Three-Dimensional Integration

The higher the degree of mean depth in the local and global visual mean depth, the greater the average from the Min Radial and Max Radial metrics. Additionally, the lower degree of visible mean depth value reflects the low integration value in the vision from the vantage point to the whole visibility system of the prayer hall due to the barriers. Table 7 shows that Al-Azhar Mosque has the least integrated three-dimensional system because it has the lowest mean depth value (7.24). Zabeel Mosque had the second-lowest level with a score of 8.26. Sheikh Zayed Mosque achieved a high integration value due to its high visual mean depth (see Figure 9e). In general, a more integrated space is an important factor in estimating the visual comfort more predictability.

5.2.5. Volumetric Elongation

Volumetric elongation indicates the longest line from the point of view to the barrier and the greatest radial distance. In this regard, Sheik Zayed Mosque achieved a more extended visual radial with a value of 123.1. On the other hand, Zabeel Mosque has a lower volumetric elongation with a value of 48.81. Contrary to common perception, mosques with linear rectangular shapes have a longer volumetric vision. It is noted that because of the spikiness in the visual elongation, the mosques with more obstacles, such as hypostyle mosques, including Al-Azhar Mosque with a value of 80.10, still express more complex and comprehensive visions. Accordingly, the perception of volumetric configuration will be increased by the high elongation 3D view concept, whereas the perception of spaciousness will be constrained by low elongation and compactness (Figure 9g).

Regarding the third question of this paper (is there a difference in volumetric visual comfort between sitting and standing conditions in the prayer hall for the same worshiper?), a one-way ANOVA statistical model compared the relationship between a height of 1 m for a seated vantage point and 1.68 m for a standing vantage point. The research revealed a negligible and non-significant ($p > 0.05$) relationship between both heights concerning all 3D isovist metrics. Accordingly, there is no difference between the heights of worshipers' vision, as seen in Table 8.

Finally, the fourth inquiry concerns comparing the selected six types of mosques in terms of receiving better sensation by integrating both spatial and volumetric visibility analysis. In short, the current study concluded with a comparative matrix to show the sequence and level of the most visually comfortable mosques regarding spatial and volumetric vision. The red items in each column indicate those measures that negatively affect visual comfort (Figure 10).

Mosques	Spatial Visibility Metrics							Volumetric Visibility metrics							Fractal	Sequence
	IA	Con.	Oc	VI	DM	SOI	IC	C.VV	T. VV	CVOI	TVOI	VMD	VVC	VE		
Type.1E	5	4	6	6	5	6	6	6	6	6	6	6	6	5	5.6	6
Type.2C	6	5	2	5	6	2	4	4	5	3	4	4	3	4	4.1	5
Type.3A	3	1	3	3	4	3	3	5	4	5	5	5	5	3	3.7	4
Type.4D	2	2	4	2	2	4	2	2	2	4	2	2	2	2	2.4	1
Type.5A	1	6	5	4	1	5	1	1	1	1	3	1	1	6	2.6	3
Type.6B	4	3	1	1	3	1	5	3	3	2	1	3	4	1	2.5	2

Figure 10. The sequence of mosques in achieving visual comfort.

In conclusion, after responding to all four questions in the current investigation, the study discovered that visual comfort might fluctuate with changes in the prayer hall's spatial and volumetric design aspects. Furthermore, there are significant differences in visual comfort between different typo-morphological mosques. For instance, Süleymaniye Mosque occupies the upper level with a central dome courtyard. Zabeel Mosque, a non-courtyard-domed square roof, ranked second. In contrast, Sheikh Zayed Mosque, with its massive courtyard and triple dome, ranked third, and the Great Mosque in Bursa, with its non-courtyard duplicated mosque pattern, ranked fourth, and Shah Mosque, with its iwan pattern, ranked fifth. Al-Azhar Mosque, with its hypostyle pattern, ranked last in achieving visual comfort.

6. Conclusions

Building shape, arrangement, and morphology influence human visual comfort and experience. This research introduces a new integrative framework for quantitatively describing mosque typo-morphologies affecting worshipers' visual comfort. To explain the visual quality of the space, isovists, including 2D and 3D fields, are used. Isovist measurements were chosen from fundamental qualitative environmental psychology theories supported by the literature. Spatial measures such as the visible spatial area, visual connectivity, spatial complexity, two-dimensional visual integration, spatial dominance, Spatial Openness Index, and spatial enclosure perform exceedingly well. Ultimately, the isovist area (IA), connectivity (Con), occlusivity (Oc), visual integration (p-value) (VI), drift magnitude (DM), Spatial Openness Index (SOI), and isovist circularity were found to be connected to 2D isovist in visibility graph analysis (VGA). As a consequence, the volumetric visibility properties of space have been investigated using a script developed by Rhino–Grasshopper for examining the most influential metrics of space volume concerning visual comfort, such as the space visible volume from both the central vantage point (CVP) and total vantage point (TVP), visibility openness index from both a single vantage point (C.VOI) and entire vantage point (T.VOI), mean visual depth (VMD), volumetric visual control (VVC), and visual elongation (VE).

The research concluded that spaciousness is one of the critical determinants of human visual comfort in the interior architectural space. Space perception is related to the spatial isovist area. It has been found that higher isovist values increase the impression of being in a larger space. The findings showed a significant direct association between visual connectivity and the area's visibility, which creates a pleasant mood. It has also been demonstrated that higher visual integration provides a stronger sense of space. Furthermore, spatial complexity affects people negatively in relaxation and relief, as higher occlusivity indicates a more complex space. However, the positive relationship between human visual comfort and surroundings is believed to be integrated between the observer's horizontal and vertical levels of vision.

The results proved that a highly visible volume could be achieved in a mosque layout design with a central domed roof formed free of barriers and obstacles. Mosque typo-morphologies with obstructions in their main prayer halls, such as hypostyle mosques, receive less visible volume due to obstacles and barriers causing spikiness in vision. Thus, the openness index will be lower. The square shape of the prayer hall with a central dome appears to have more visual control as the mass of the visible area can be viewed from most vantage points concerning the general order of the prayer hall layout, ultimately giving high visual comfort to worshipers. In summary, the typo-morphology of mosques, which includes both spatial design metrics and volumetric design metrics, might impact worshipers' visual comfort. Ultimately, if the 3D visual volume accurately reflects the openness of space, does greater 3D visual volume indicate higher visual comfort? This study will provide a new concept that opens horizons for future research.

Author Contributions: L.A.A.: collected data; prepared, reviewed, and discussed the literature; participated in developing the methodology; and wrote the first draft of the manuscript. F.A.M.: initiated and supervised the entire project, including conceptual development, process, revision, editing, and manuscript finalization. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All data generated or analyzed during this study are included in this article.

Acknowledgments: We appreciate everyone who helped with this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Song, Y.; Mao, F.; Liu, Q. Human comfort in indoor environment: A review on assessment criteria, data collection, and data analysis methods. *IEEE Access* **2019**, *7*, 119774–119786. [CrossRef]
2. Johnson, P.A. *The Theory of Architecture: Concepts, Themes and Practices*; Wiley: New York, NY, USA, 1994.
3. Kim, Y.O. *Spatial Configuration, Spatial Cognition and Spatial Behaviour: The Role of Architectural Intelligibility in Shaping Spatial Experience*; University of London: London, UK; University College London: London, UK, 1999.
4. Démuth, A. *Perception Theories*; Trnavská Univerzita: Kraków, Poland, 2013; Volume 2549.
5. Hillier, B.; Hanson, J. *The Social Logic of Space*; Cambridge University Press: Cambridge, NY, USA, 1984. [CrossRef]
6. Turner, A.; Maria, D.; David, O.; Alan, P. From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space. *Environ. Plan. B* **2001**, *28*, 103–121. [CrossRef]
7. Khan, H.U. The architecture of the mosque, an overview and design directions. In *Expressions of Islam in Buildings*; Salam, H., Ed.; Concept Media/The Aga Khan Award for Architecture: Singapore, 1990; pp. 109–127.
8. Okuyucu, S.E. Evaluation of spatial fictions, design concepts, aesthetic quests of traditional, modern mosques from past to present and the analysis of mosque samples. *Civ. Eng. Archit.* **2016**, *4*, 54–66. [CrossRef]
9. Macaulay, D. *Mosque*, 1st ed.; Houghton Mifflin Harcourt: Boston, MA, USA, 2008.
10. Franz, G.; Wiener, J.M. From space syntax to space semantics: A behaviorally and perceptually oriented methodology for the efficient description of the geometry and topology of environments. *Environ. Plan. B Plan. Des.* **2008**, *35*, 574–592. [CrossRef]
11. Ostwald, M.J.; Dawes, M.J. Using isovists to analyse architecture: Methodological considerations and new approaches. *Int. J. Constr. Environ.* **2013**, *3*, 85–106. [CrossRef]
12. Dosen, A.S.; Ostwald, M.J. Lived space and geometric space: Comparing people's perceptions of spatial enclosure and exposure with metric room properties and isovist measures. *Archit. Sci. Rev.* **2016**, *60*, 62–77. [CrossRef]
13. Sedlmeier, A.; Feld, S. Learning indoor space perception. *J. Locat. Based Serv.* **2018**, *12*, 179–214. [CrossRef]
14. Batty, M. Exploring isovist fields: Space and shape in architectural and urban morphology. *Environ. Plan. B Plan. Des.* **2001**, *28*, 123–150. [CrossRef]
15. Fisher-Gewirtzman, D.; Shach Pinsly, D.; Wagner, I.A.; Burt, M. View-oriented three-dimensional visual analysis models for the urban environment. *Urban Des. Int.* **2005**, *10*, 23–37. [CrossRef]
16. Fisher-Gewirtzman, D. Internal space layout and functionality as a major aspect influencing visual analysis for environmental and urban systems. *WIT Trans. Ecol. Environ.* **2010**, *129*, 431–442.
17. Koltsova, A.; Tunçer, B.; Schmitt, G. Visibility analysis for 3D urban environments. In Proceedings of the 2013 eCAAde, Delft, The Netherlands, 18–20 September 2013; Models of Computation: Human Factors, Computation and Performance; Delft University of Technology: Delft, The Netherlands, 2013; Volume 2, pp. 375–383.

18. Fisher-Gewirtzman, D.; Natapov, A. Different approaches of visibility analyses applied on hilly urban environment. *Surv. Rev.* **2014**, *46*, 366–382. [CrossRef]
19. Golub, D.; Doytsher, Y.; Fisher-Gewirtzman, D. 3D visibility analysis indicating quantitative and qualitative aspects of the visible space. *Surv. Rev.* **2018**, *50*, 134–146. [CrossRef]
20. Dalton, N.S.; Dalton, R.C.; Marshall, P.; Pewerett, I.; Clinch, S. Three dimensional isovists for the study of public displays. In Proceedings of the SSS10, 10th International Space Syntax Symposium, London, UK, 13–17 July 2015.
21. Ünlü, A.; Edgü, E.; Şalgamcıoğlu, M.E.; Çanakçioğlu, N.G.; Yılmaz, E.A. Isometric measurands on perceived spaciousness: Exploring volumetric isovist. In Proceedings of the 12th International Space Syntax Symposium, SSS 2019, Beijing, China, 8–13 July 2019.
22. Krukar, J.; Manivannan, C.; Bhatt, M.; Schultz, C. Embodied 3D isovists: A method to model the visual perception of space. *Environ. Plan. B Urban Anal. City Sci.* **2021**, *48*, 2307–2325. [CrossRef]
23. Al-Jameel, A.H.; Al-Moula, E.K. Using Three Dimensional Isovist to Detect the Property of Surprise in Architectural Artifacts: Islamic Architecture as A Context. *Eurasian J. Sci. Eng.* **2023**, *9*, 14–32. [CrossRef]
24. Ismail, A.M.; Khalil, H.B.; Mostafa, A. The Soul of Mosques. Mosque Architecture Present Issues and Future Ideas. In Proceedings of the International Conference on Mosque Architecture 2019, Kuala Lumpur, Malaysia, 25–27 November 2019.
25. Metwally, E. Achieving the visual perception and gestalt psychology in sultan Hassan Mosque building. *Open J. Appl. Sci.* **2021**, *11*, 21–40. [CrossRef]
26. Mustafa, F.A.; Rashid, S.J. Studying the human scale and proportionality of Mosque buildings: Some selected case studies in Erbil city. *J. Islam. Archit.* **2019**, *5*, 129–136. [CrossRef]
27. Kassim, N.; Taib, Z.M. Users' perception on application of ornamentation motif between excessive and minimal decorated praying hall of community mosque. *Procedia-Soc. Behav. Sci.* **2014**, *153*, 99–105. [CrossRef]
28. Ahmadi, M.; Farkisch, H.; Ahmadi, V.; Khoshnevis, A.M.K. An Insight into the Interrelation between the Mosques' Architectural Codes and the Quality of Worshipers' Presence of the Heart: A Case Study of the Safavid Mosques in Isfahan. *Cult. Islam. Archit. Urban. J.* **2020**, *5*, 51–74. [CrossRef]
29. Abbaszadeh, M.J.; Zamani, B. Evaluating Environmental Factors Affecting the Genesis of a Sense of Holy Space in Mosques: Case Studies of Bazar-e-Tehran Mosque, Tehran University Mosque, Al-Jawad Mosque of Tehran. *Cult. Islam. Archit. Urban. J.* **2020**, *5*, 105–121.
30. Abbaszadeh, M.; Sultan, Q.S.; Mohajer, M.A. The Influences of Physical Features of Space on Sense of Place (Case study: Prayer Rooms of Mehrabad International Airport). *Int. J. Archit. Urban Dev.* **2015**, *5*, 23–32.
31. Tarabieh, K.; Nassar, K.; Abu-Obied, N.; Malkawi, F. The statics of space syntax: Analysis for stationary observers. *ArchNet-IJAR Int. J. Archit. Res.* **2018**, *12*, 280–306. [CrossRef]
32. Arslan, H.; Yildirim, K. Perceptual Evaluation of the Mosque Facades of Different Periods: Preference, Complexity, Impressiveness, and Stimulative. *Megaron* **2017**, *12*, 511–523. [CrossRef]
33. Sezer, F.S.; Kaymaz, E. The user's perception of indoor comfort conditions in historical mosques: The case of Bursa, Turkey. *Int. J. Humanit. Soc. Sci.* **2016**, *6*, 43–54.
34. Ghouchani, M.; Taji, M.; Kordafshari, F. The effect of qibla direction on the hierarchy of movement in mosque: A case study of mosques in Yazd, Iran. *Front. Archit. Res.* **2016**, *8*, 396–405. [CrossRef]
35. Malhis, S. Narratives in Mamluk architecture: Spatial and perceptual analyses of the madrassas and their mausoleums. *Front. Archit. Res.* **2016**, *5*, 74–90. [CrossRef]
36. Adli, L.C.; Chemrouk, N.C. On drafting a new architectural syntax: Case study of the great mosque of Algiers. *J. Islam. Archit.* **2015**, *3*, 106–114. [CrossRef]
37. Munro, K.; Grierson, D. Towards the development of a space/nature syntax at Arcosanti. *Open House Int.* **2016**, *41*, 48–55. [CrossRef]
38. Yaseen, F.R.; Mustafa, F.A. Visibility of nature-connectedness in school buildings: An analytical study using biophilic parameters, space syntax, and space/nature syntax. *Ain Shams Eng. J.* **2023**, *14*, 101973. [CrossRef]
39. Stamps, A.E. Isovists, Enclosure, and Permeability Theory. *Environ. Plan. B Plan. Des.* **2005**, *32*, 735–762. [CrossRef]
40. Dem Bayram, Ç.İ.Ğ.; Lu, Ş. Examining the Occluded Space in a Museum Gallery through User's Cognition and Space Morphology. In Proceedings of the 13th Space Syntax Symposium, Bergen, Norway, 20–24 June 2022. [CrossRef]
41. Craig, D.M. Review of "Reviews Vision, by David Marr" San Franclsco: WH Freeman, 1982. *ACM SIGDOC Asterisk J. Comput. Doc.* **1983**, *9*, 5–7. [CrossRef]
42. Gibson, J.J. *The Ecological Approach to the Visual Perception*; Houghton Mifflin: Boston, MA, USA, 1979.
43. Gibson, J.J. *Reasons for Realism: Selected Essays of James J. Gibson*; Lawrence Erlbaum Assoc Incorporated; Lawrence Erlbaum Associates LEA Publishers: London, UK, 1982.
44. Wang, Z.; Nagai, Y.; Zhu, D.; Liu, J.; Zou, N. Based on Creative Thinking to Museum Lighting Design Influences to Visitors Emotional Response Levels Theory Research. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *573*, 012093. [CrossRef]
45. Madhusanka, B.G.D.A.; Jayasekara, A.G.B.P. Design and development of adaptive vision attentive robot eye for service robot in a domestic environment. In Proceedings of the 2016 IEEE International Conference on Information and Automation for Sustainability (ICIAfS), Galle, Sri Lanka, 16–19 December 2016; IEEE: Piscataway, NJ, USA, 2016; pp. 1–6.
46. Benedikt, M.L. To take hold of space: Isovists and isovist fields. *Environ. Plan. B Plan. Des.* **1979**, *6*, 47–65. [CrossRef]

47. Morello, E.; Ratti, C. A digital image of the city: 3D isovists in Lynch's urban analysis. *Environ. Plan. B Plan. Des.* **2009**, *36*, 837–853. [CrossRef]
48. Indraprastha, A.; Shinozaki, M. Computational models for measuring spatial quality of interior design in virtual environment. *Build. Environ.* **2011**, *49*, 67–85. [CrossRef]
49. Penn, A.; Treleavan, P.; Hillier, B.; Bull, L.; Conroy-Dalton, R.; Dalton, N.; Dekker, L.; Mottram, C.; Turner, A. *Pangea V2.1b CD and Pangea User Manual [Software]*; University College London: London, UK, 1996.
50. Thiel, P. *People, Paths, and Purposes: Notations for a Participatory Envirotecture*; University of Washington Press: Seattle, DC, USA, 1997.
51. Teller, J. A spherical metric for the field-oriented analysis of complex urban open spaces. *Environ. Plan. B Plan. Des.* **2003**, *30*, 339–356. [CrossRef]
52. Derix, C.; Gamlesæter, Å.; Carranza, P.M. 3d Isovists and Spatial Sensations: Two methods and a case study. In *Movement and Orientation in Built Environments: Evaluating Design Rationale and User Cognition*; University of Freiburg: Freiburg, Germany, 2008; pp. 67–72.
53. Bhatia, S.; Chalup, S.K.; Ostwald, M.J. Analyzing architectural space: Identifying salient regions by computing 3D isovists. In Proceedings of the 46th Annual Conference of the Architectural Science Association (AN-ZAScA), Gold Coast, Australia, 14–16 November 2012.
54. Varoudis, T.; Psarra, S. Beyond two dimensions: Architecture through three-dimensional visibility graph analysis. *J. Space Syntax* **2014**, *5*, 91–108.
55. Gibson, J.J. *The Senses Considered as Perceptual Systems*; Houghton Mifflin: Boston, MA, USA, 1966.
56. Koutsolampros, P.; Sailer, K.; Varoudis, T.; Haslem, R. Dissecting Visibility Graph Analysis: The metrics and their role in understanding workplace human behavior. In Proceedings of the 12th International Space Syntax Symposium, Beijing, China, 8–13 July 2019; Volume 12.
57. Franz, G.; Wiener, J.M. Exploring isovist-based correlates of spatial behavior and experience. In Proceedings of the 5th International Space Syntax Symposium, Delft, The Netherlands, 13–17 June 2005; TU Delft Press: Delft, The Netherlands, 2005.
58. Wiener, J.M.; Franz, G.; Rossmanith, N.; Reichelt, A.; Hanspeter, A.M.; Bülthoff, H.H. Isovist Analysis Captures Properties of Space Relevant for Locomotion and Experience. *Perception* **2007**, *6*, 1066–1083. [CrossRef]
59. Bokharei, S.; Nasar, J.L. Perceived Spaciousness and Preference in Sequential Experience. *Hum. Factors* **2016**, *58*, 1069–1081. [CrossRef]
60. Wise, J.A. *The Quantitative Modeling of Human Spatial Habitability*; (No. NASA-CR-179716); NASA: Washington, DC, USA, 1985.
61. Hillier, B. *A Configurational Theory of Architecture*; Cambridge University Press: Cambridge, UK, 1996.
62. Turner, A. *Depthmap 4—A Researcher's Handbook*; University College London: London, UK, 2004; pp. 9–19.
63. Conroy, R. *Spatial Navigation in Immersive Virtual Environments*; University of London: London, UK; University College London: London, UK, 2001.
64. Sengke, M.M.; Atmodiwirjo, P. Using isovist application to explore visibility area of hospital inpatient ward. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *185*, 012008. [CrossRef]
65. Giseop, K.I.M.; Ayoung, K.I.M.; Youngchul, K.I.M. A new 3D space syntax metric based on 3D isovist capture in urban space using remote sensing technology. *Comput. Environ. Urban Syst.* **2019**, *74*, 74–87.
66. Zook, J.B. Spatial Schemata in Museum Floorplans. In Proceedings of the 11th International Space Syntax Symposium 2017, Lisbon, Portugal, 3–7 July 2017.
67. Ali, L.A.; Mustafa, F.A. The state-of-the-art knowledge, techniques, and simulation programs for quantifying human visual comfort in mosque buildings: A systematic review. *Ain Shams Eng. J.* **2023**, *14*, 102128. [CrossRef]
68. Ali, L.A.; Mustafa, F.A. Mosque Typo-Morphological Classification for Pattern Recognition Using Shape Grammar Theory and Graph-Based Techniques. *Buildings* **2023**, *13*, 741. [CrossRef]