TYPE Original article
DOI http://dx.doi.org/10.21271/ZJPAS.37.5.10

OPEN ACCESS

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RECEIVED :25 /12 /2024
ACCEPTED :17/05/ 2025
PUBLISHED :31/ 10/ 2025

KEYWORDS:
Mosque Typo-morphology; Visual comfort; Visibility; Visual field; Virtual reality (VR)

The Impact of Mosque Typo-Morphology on Users' Visual Comfort

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ABSTRACT

Visual comfort is a fundamental human goal impacted by the perception of interior architectural geometry via vision as one of five human sensors. The geometrical and spatial qualities of an architectural space, including area, size, dimension, volume, and human scale, among others, affect the perceived space. Furthermore, it is necessary to note that daylight influences the perceived indoor space. The mosque was the most important building in Islamic civilization because it serves as the principal place of worship. The prayer hall (or haram) is an essential part of the mosque. Mosque typo morphology is the focus of this research, which examines the building from a spatial and volumetric perspective. This study investigates how prayer hall's most popular typo-morphological characteristics may affect users' visual comfort. This study examines mosque typo-morphological design using mixed-method qualitative and quantitative evaluations. A qualitative method was used to describe the mosques through architectural drawings. A quantitative questionnaire survey was conducted to receive experts' feedback on mosque visual comfort satisfaction using VR. The study's findings indicate that creating spatial openness and visible volume in prayer hall configurations clear of obstacles and effective integration with monumental scale and vertical visual proportion significantly impacts visual comfort. The study concluded that the levels of visual comfort in mosque prayer halls differ according to the typo-morphological design characteristics of mosques. The current study contributed to linking the known mosque prototypes and the level of visual comfort for users through an in-depth comparative-analytical study.

1.Introduction

Buildings must mainly satisfy human comfort standards within an interior setting. This relates to establishing a state of physical, perceptual, and psychological comfort, sometimes characterized as the lack of discomfort. The effectiveness of the indoor environment is dependent upon four principal factors: thermal comfort, visual comfort, acoustic comfort, and indoor air quality. Maslow's Hierarchy of Needs categorizes comfort as a basic necessity, integral to physiological well-being. (Johnson, 1994). In the field of building physics, the concept of comfort was previously examined inside the realm of architecture. From this point of view, the visual comfort of a built environment is just as important as any other physical. need.

The geometrical and spatial characteristics of the architectural space—its length, height, volume, balance, permeability, and angle of view—affect the individual's feedback of visual comfort, which in turn influences their feelings of spaciousness and consciousness. Multiple studies on architectural contexts have consistently demonstrated the effectiveness of visibility analysis. Developing a comprehension of the spatial and visual relationships within the built environment is important (Hillier and Hanson, 1989; Turner *et al.*, 2001), that control movement, facilitate social interactions, generate attractive perspectives, and highlight significant environments. Typology is an important approach for analyzing the spatial characteristics of the built environment. Another field that deals with the study of the geometry of space and its relationship to architectural form is morphology (Khan, 1990). The typo-morphological study was chosen to involve the integration of two fundamental forms of research: the typological study, which focuses on syntactical and spatial analysis, and the morphological study, which focuses on form analysis.

The mosque has always been the most important building in Islamic history and is still useful to Islamic institutions. The mosque primarily serves as a place for private and public worship and an important center for religious education. The prayer hall, also known as the haram, is a crucial architectural element of a mosque as it is the primary space for religious worship (Macaulay,2008). Moreover, the design and layout of the prayer hall play a significant part in shaping the patterns and architectural form of mosques (Okuyucu, 2016).

Many studies contacted mosques design characteristics, its layout configuration and users experience and behavior. Nevertheless, a very few studies try to combine the effect of space typo- morphology and its daylighting on worshippers' visual comfort. This study aims to analyze the influence of typo-morphological design components and daylighting on the visual comfort sensed by worshippers. The visual comfort conditions of the inside prayer hall, including the users' sense of spaciousness and consciousness, will differ as a result of the mosque's geometric form and its interior patio – volumetric shape.

2. Literature review

Many studies conducted mosques analysis in various field of study. The current study investigates on visual perception within mosques, examinations of visibility analytic methods and techniques, assessments of daylighting in indoor built environments, and daylighting performance within mosques. This is to extract and identify the research gap in order to formulate the research problem, aim, and objectives. The study by (Ismail, Khalil and Mostafa, 2019) examines how the syntactical aspects of several significant old Cairo mosques created calm. The study concluded that mosques' spatial design and layout have a favorable relationship with spirituality. Similarly, (Mustofa and Rashid, 2019) overarching goal is to demonstrate whether or not mosques in Erbil city from varying periods focused on a human scale and proportion to attain aesthetics and psychological comfort within their prayer halls. In the same vein, (Tarabieh *et al.*, 2018) examined the spatial logic of a typical "static space" as a typical design for a prayer hall containing a space with dual symmetry and four columns since many religious buildings have this layout. The result shows that increased variation in column location has a noticeable effect on the users' experience in the prayer hall. In addition, (Malhis, 2016) examined the spatial and physical characteristics attempting to convey the story behind their formations. This study focused on the configuration articulation and the relationship between the geometry of space and its perceived experience. At length, Abbaszadeh and his colleagues' study aims to identify the important components of space that influence how users perceive a prayer hall in terms of its physical attributes. The results show that the physical features of environments do not greatly influence one's feeling of place (Abbaszadeh, SULTAN and MOHAJER, 2015).

On the other hand, several studies are dedicated to the studies that relate to the visibility design metrics in indoor built environments. These metrics involve spatial visibility, as well as volumetric visibility. (Krukar *et al.*, 2021) focused on an embodied 3D isovist that is based on the notion of spatial artifacts and predicts human perception of space more accurately than the generic volumetric space, especially in terms of spaciousness and complexity. the study concluded that these impacts are less significant in the overall assessment of a building's spaciousness and complexity after applying virtual reality to the chosen space for analyzing the visibility of space. Moreover, (Dosen and Ostwald, 2016) examine the connection between perceptions of enclosure and exposure and geometric measurements of the same space. The result generally supports the notion that the physical space is not only perceived and evaluated but also that past experience influences perceptions and preferences. Interestingly, (Varoudis and Psarra, 2014) demonstrate how to generate a graph of inter-visible locations on a planar surface that integrates three-dimensional element relationships. Accordingly, the most effective factors of space visibility and visual comfort have been examined as well as the most important methods of calculating visibility analysis have been presented.

Light plays a crucial role in enhancing the attractive, aesthetic, and functional aspects of mosque interior spaces in addition to their spiritual significance. (Matracchi, 2021) examined how religious buildings utilize light to create a spiritual experience. Developed a standard visual questionnaire using a statistical population of experts and regenerated the Nasir Al-Mulk Mosque in Shiraz's interior light intensity. The findings show that Islamic architecture emphasizes light symbolically (Matracchi, 2021). Once more, The research conducted by (Hareri and Alama , 2020) thoroughly examines the structural design methodologies employed in mosques to create the impressive lighting that creates a feeling of place for individuals. Furthermore, it analyzed the accessibility and effectiveness of daylighting and the influence of the Qibla axis on the design of two mosque types: a historic mosque and a contemporary mosque. In addition, (Tarabieh *et al.*, 2019) use a single mosque prototype with multiple configurations to evaluate the relationship between column locations, their spatial impact, and the size and location of the openings while analyzing the north facade with the most significant daylight potential. Interestingly, A systematic search was used to identify and analyze eligible research and studies in (Ali and Mustafa, 2023c) systematic review. About 106 relevant works were thoroughly investigated, and the summary was based on five points: objective, influential variables, method, case study, and findings. A complete literature review covered visual comfort assessment, daylighting parameters, and spatial and visual design aspects. The study found a gap in knowledge on a complicated link of three areas of interest; the assessment of internal visual comfort, analysis of daylighting, and typo-morphological analysis of mosques. As shown in Fig.1.

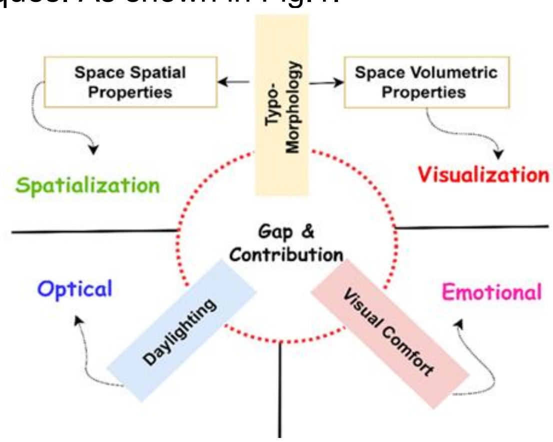


Fig.1. Research gap and contribution (Researcher)

Overall, many studies have addressed mosques' ideas and design principles, while no study has been done on how to integrate three elements (mosque typo-morphology, daylighting, and visual comfort) into the framework of mosque typology and compare mosques with various typo-morphological patterns. This study aims to develop a comprehensive conceptual framework for examining the possible effects of the relationship between the variety of typo-morphological characteristics of mosque buildings and the level of visual comfort satisfaction within the main prayer halls, particularly in the main mosque prototypes.

Accordingly, to achieve the main goal, the research formulated the following inquiries to be addressed by the end of the study.

1. Is there a relationship between mosque building morphology and visual comfort?
2. With the difference in typo-morphology of mosques, what are the spatial -morphological characteristics most affecting users' visual comfort inside the prayer hall?
3. To what extent do the spatial-morphological characteristics of a mosque have a causal influence on visual comfort, specifically in terms of spaciousness and consciousness?

3. Mosque architecture

Mosques are unique places set aside for worship and prayer. They are some of the most famous buildings in nations with a predominantly Muslim population and often serve as points of interest and landmarks in urban settings. Mosques may be found in various architectural styles, each incorporating elements from earlier periods to create novel variations on traditional mosque layouts and designs. (Alkhaled, 2019).

3.1. Mosque Component

Mosques have historically served religious, societal, political, and legal purposes. There are two types of mosques: the masjid Jami, or "collective mosque," a large state-controlled mosque that is the center for community worship and Friday prayers, as well as other religious events, and the smaller masjid, which is built and managed by the community and used for five daily prayers (Omer, 2008). Additionally, the mosque is a multipurpose public space in which worshippers do various activities (Okuyucu, 2016; Tarabieh *et al.*, 2018). Functional and symbolic architectural mosque components will be studied in the current research.

A. Mosque Main Functional Components

The prayer hall, known as Bait as-Salah in Arabic, is a significant area for worship and prostration in mosques (Budi, 2006; Budi and Wibowo, 2018). Its rectangle or square shape may be covered by a flat or domed roof that requires multiple columns.

Qibla wall, Mihrab, Minbar: Qibla wall: prayer hall wall facing Mecca. The qibla wall will include a mihrab and minbar, with the longest side facing Mecca (Budi, 2006; Budi and Wibowo, 2018).

Al-Minbar: a raised platform in front of a mosque where the imam delivers sermons or addresses. The area to the right of the mihrab indicates the qibla prayer (Okuyucu, 2016).

The entrance serves as a barrier between the inside and outside. Visitors are welcomed at mosque entrances (Othman and Zainal-Abidin, 2011).

The courtyard was an integral part in the Prophet's Mosque's original design. It links public and sacred spaces. It also serves as an additional site for Friday prayers (Abdulhamid, Sabr Qadir and Ali, 2016). The most typical mosque courtyard shape is rectangular. According to design, arcades and flat-roofed porticos (Riwaq) surround the courtyard. The courtyard with four Iwans is yet another form of courtyard found in Iwan Mosque designs (Asfour, 2016).

The corridor is an extension of the mosque's center form. Shaded corridors are always included in buildings to cool external air before entering (Othman and Zainal-Abidin, 2011).

Mosques have several functional components, including ablution areas, libraries, storage, rooms, which vary from mosque to mosque (Abdulhamid, Sabr Qadir and Ali, 2016).

B. Mosques Symbolic Components

Some components are symbolic of mosque design. Though previously unpopular, the dome and minaret are now common symbolic parts of mosque architecture.

Dome: The dome is known in Arabic as a (Qubba) and most mosques include at least one. Regardless of the origins of the dome, it has always been seen as a symbolic element in many religious civilizations. In addition, Mosque design may also be differentiated by various dome shapes and numbers such as spherical, elliptical, bulbous, and onion-shaped domes (Asfour, 2016).

Minaret: The term "minaret" is derived from the word "Manrah," which means "lighthouse". The minaret is the most prominent vertical component in mosque architecture. It is the tower from which the prayer call is traditionally made five times daily, nowadays, sound speakers have taken their place. Its primary role remains as a visual focal point distinguishing the mosque from its surrounding buildings. Historically significant mosques typically have minarets with various design and architectural elements (Asfour, 2016).

Iwan: The Iwan is a distinguishing feature of Islamic architecture. Architecturally, it relates to one meaning: architectural majesty (Rabat, 2002). Its structure has three walls capped by a tremendously high arch and a roof exposed from its front façade (Shamaileh, 2021). Fig.2 provides more detail

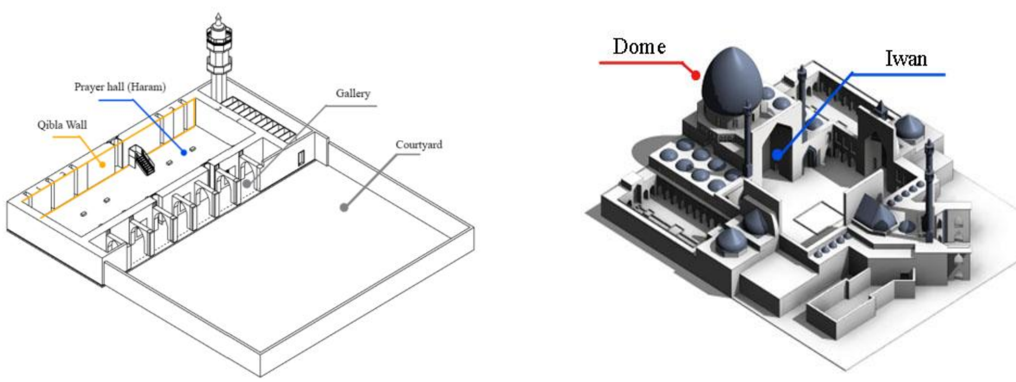


Fig. 2 Mosque’s most essential component (Ali and Mustafa, 2023b)

3.2. Mosque Typo-Morphological classification

Typo morphology is an area of study that combines two important approaches: typological analysis, which focuses on the which examines syntactic and spatial aspects, and morphological analysis, which studies the form characteristics. Typo-morphology refers to the examination of the spatial and geometrical characteristics of buildings. Ali and Mustafa cited numerous research on mosques that focus on the historical and architectural aspects. These studies employ various classifications to evaluate the layout designs of mosques for diverse reasons, such as geographical, historical, typological, and morphological considerations. A systematic procedure of extraction and prototyping is employed by (Ali and Mustafa, 2023b) to find and classify the syntactic and morphological characteristics for each sub-category within the classification of mosques' typo morphology. The study concluded with the identification of six primary and twenty-one subsidiary typo-morphological prototypes of mosques. As illustrated in Fig.3.

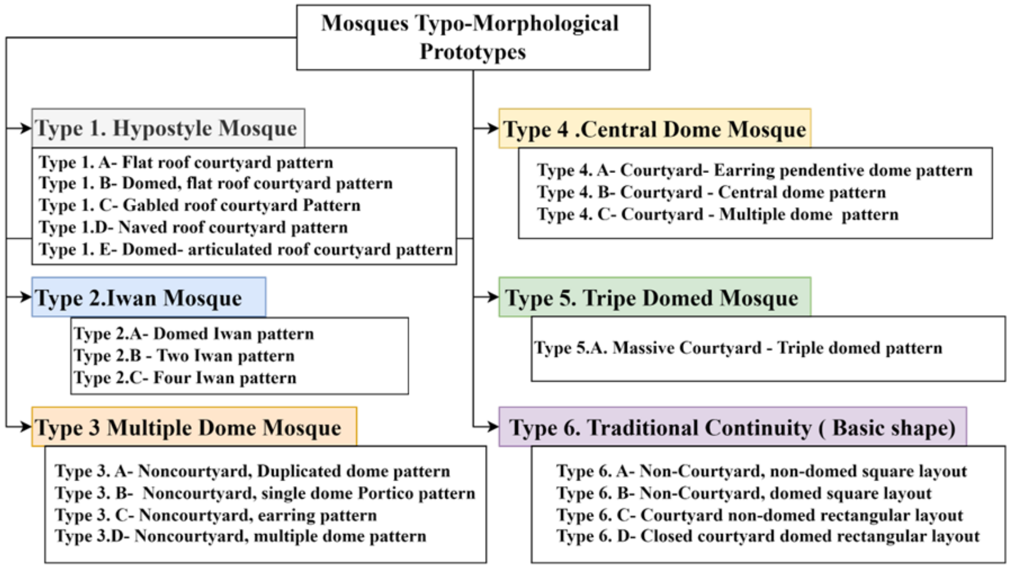


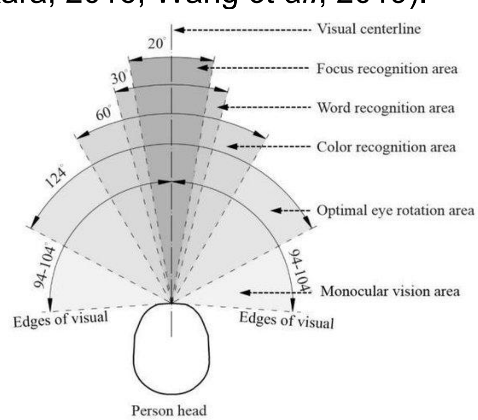
Fig. 3. Mosque typo-morphology prototypes (Ali and Mustafa, 2023b)

4. Visual comfort in architecture

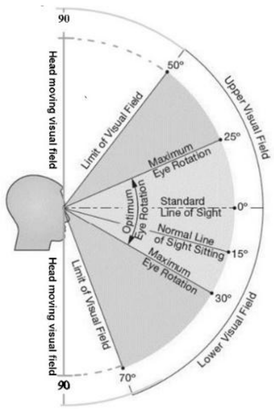
As the primary source of environmental information, perception is responsible for all human and environmental interactions. Moreover, since perception is linked to the environment and its physical attributes, which serve as stimuli, this explains why some individuals find specific architectural structures more visually appealing than others. In addition, there is perceptible space, which connects the inner and outer environments (human environment) which are created by the interaction of the senses (vision, hearing, scent, touch, and taste) with environmental stimuli (Victor and Popow, 2000). Vision is one of the most important senses for perceiving the environment, which can be negatively or positively affected by the level of light, and plays a significant role in determining whether an indoor space is more or less visible to occupants (Moscoso *et al.*, 2022). Additionally, the indoor environment design characteristics specify the range of visibility for the occupants. As well as daylighting characteristics have been identified as having a close positive relationship to visual comfort.

4.1. Indoor Space Visibility

The visual field in an indoor architectural setting is influenced by human movement and the angle of vision. The majority of individuals have a horizontal central field of vision ranging from 50° to 60°, allowing an object to be perceived by both eyes continuously within this area. This produces a more intense central field that each eye can perceive independently (Gibson, 1979). Moreover, images are clear, depth is seen, and colors can be identified while considering them within the "binocular field," which is the middle area of vision. However, monocular vision can range from 90o to 104o on both the left and right boundaries of vision. Similarly, the horizontal or 0° is the standard definition of a line of sight in the vertical field of view. The natural line of sight of a person is usually 10 or 15 degrees below the horizontal line. Furthermore, the limited vision field is around 120 o, with 50o above and 70o below the horizontal line. Meanwhile, with head and neck movement, the whole vertical visual field can exceed 180o Fig. 4 (Madhusanka and Jayasekara, 2016; Wang *et al.*, 2019).



a.



b.

Fig. 4. a) Human horizontal vision angles (Wang *et al.*, 2019), b) Human vertical vision angles (Adapted from (Madhusanka and Jayasekara, 2016))

4.2. Architectural Space Factors for Visual Comfort

The shape and structure of environments influence human visual comfort, spatial behavior, and experiences. Thus, description systems that mirror the human response to the crucial qualities of space will undoubtedly be helpful in architecture and spatial-visual cognition. James J. Gibson and his ecological approach developed an original perceptual strategy inside this framework. He defines the visual environment as a surrounding "layout of surfaces" that defines the perceived space, while the perception of the environment resembles an interaction of light rays coming from various angles towards a potential observation point, designating the arrangement of rays by intensity and wavelength as the "optic array." Overall space visibility factors relate to two primary features as follows:

4.2.1. Spatial visibility

The concept of spatial visibility comprises many aspects such as the ***(a) spatial visibility area***, which also specifies the Isovist's surface area. In other words, from the vantage point, a larger size is more visible (Benedikt, 1979; Sedlmeier and Feld, 2018; Koutsolampros *et al.*, 2019). In this vein, Bokharei and Nasar (2016) discovered that perceived spaciousness is connected to spatial isovist area. ***(b) visual connectivity***, (Hillier and Hanson, 1989) defines visual connection as the degree to which one place is visible from its neighbors based on the shortest and longest line of sight. (***c) Spatial Complexity***, space complexity and influence people's tranquility and relaxation. ***(d) integration***; lead to the architectural integration of the space ***(e) spatial control***, (Turner *et al.*, 2001) describe Visual Control as the VGA implementation of the 'Control' metric proposed by (Hillier and Hanson, 1989). It is determined by combining the inverses of the neighborhood sizes adjacent to the vertex (Koutsolampros et al., 2019). ***(f) Spatial Openness Index***; This is a quantitative assessment of visual-spatial information applied to compare various spatial configurations and ***(g) circularity***, which denotes the roundness of perceived space. This quality is believed to enhance the serene experience of expansiveness while offering a sense of enclosure (Stamps, 2005).

4.2.2. Volumetric visibility

There are several potential metrics for determining indoor 3D visibility. Here, the study will suggest the most crucial volumetric or three-dimensional visibility directly correlating to human visual comfort in the interior built environment (Ali and Mustafa, 2023a). These incorporate the ***(a) visible volume;*** The amount of visible volume has been linked to isovist qualities, with visual comfort described as an isovist area extension (***b) volumetric openness index;*** The ratio of visible volume to total volume, ***(c) visual spikiness;*** In 2005, Franz and Wiener found a strong link between jaggedness (or spikiness) and a sense of space. The spikiness of a given area can be measured by its visible volume ratio from a single vantage point (Franz and Wiener, 2005). ***(d) visual control;*** It is sometimes called the "center of gravity" or "center of vision weight". It is where the highest number of radial lines cross, making the region visible from the most significant number of perspective points ***(e) human scale;*** A relationship with the human scale substantially determines the visual perception of space (Gaudieri, 2020). ***(f) volumetric proportion;*** The form of the space is a crucial enclosure impacting our visual ability, particularly the proportion between the dimensions of space in assessing the degree of perception, and ***(g) Elongation;*** which indicates the maximum radial distance, signifying the longest line from the observer to the barrier. Consequently, the elongation ratio and compactness are two further factors that affect the perception of volumetric configuration and the limits of spaciousness (Wise, 1985; Stamps, 2011).

4.3 Psychological Factors for visual comfort

Humans can feel visual comfort physically and psychologically. Meanwhile, perception or sense is the ability to perceive one's surroundings through sensations. Current research examines the two primary psychological indices:

4.3.1. Consciousness

Emotional experiences, according to the James-Lange theory, are experienced physiological body changes. This method has recently been revived and modified in both neuroscientific and philosophical views of emotional experience representation (Northoff, 2008). It is commonly understood as a condition of calm, tranquility, and oneness. Furthermore, Spirituality is defined by (Ismail, Khalil and Mostafa, 2019). as “a spiritual experience of inner peace, the calmness induced by the physical presence within the spaces of a place of worship.”. It explores how specific architectural elements might stimulate brain areas linked to spirituality and contemplation (Sadeghi Habibabad *et al.*, 2022). According to him there is a connection between awareness, spatiality, serenity and visual comfort experienced by user in mosques, which may be attributed to the influence of light.

4.3.2. Spaciousness

The term "spaciousness" is etymologically linked to the word "space," which refers to the extent of adequacy and sufficiency of physical area. Specifically, it describes the degree of expansiveness or roominess existent within a given space (Ezzeldin, Assem and Abdelmohsen, 2021). The feeling of spaciousness is a criterion that influences perspective and wayfinding and is influenced by architectural space formal characteristics such as length, height, volume, solid/void balance, permeability, and angle of view. Several indices have been used to define spaciousness. First is the area’s attractiveness, which gives people an excellent impression and possibly a homely character. Second, consider the interiors; their order, balance, and coordination contribute to their impressiveness. Last, the significance and meaning of the space's configuration, complexity, and other elements give a sense of contemplation. (Stamps, 2009). Hence, the sense of spaciousness is not just determined by physical attributes but rather may be subjective when individuals assess it based on their views or objective when it is linked to the physical qualities of space through the utilization of programs (Ozdemir, 2010; Al-Zamil, 2017).

4.4. Daylighting

In general, daylighting has been investigated by evaluating some characteristics that describe the interaction between human requirements and the lighting environment. Several studies have discussed the key daylight measures in this context. In their review article, (Ali and Mustafa, 2023c) Defined four critical metrics: (a) The quantity of daylight or the amount of daylight; the physical amount is often used to represent how much light reaches a particular place on a surface (b) Glare; is a light phenomenon that makes it difficult for individuals to see in bright environments owing to excessive artificial or natural lighting (c) The quality of daylight; refer to the properties and physical characteristics of light and (d) The uniformity of daylight; refer to the distribution of light in an area (Carlucci *et al.*, 2015).

In summary, the architectural space visibility variables primarily revolve around two aspects: spatial visibility. On the contrary, the visual comfort factors that demonstrated the highest effectiveness were shown as consciousness and spaciousness. Fig. 5 provides a comprehensive overview of the key metrics used to assess architectural space visibility concerning human visual comfort, encompassing both two-dimensional (2D) and three-dimensional (3D) visibility. And daylighting.

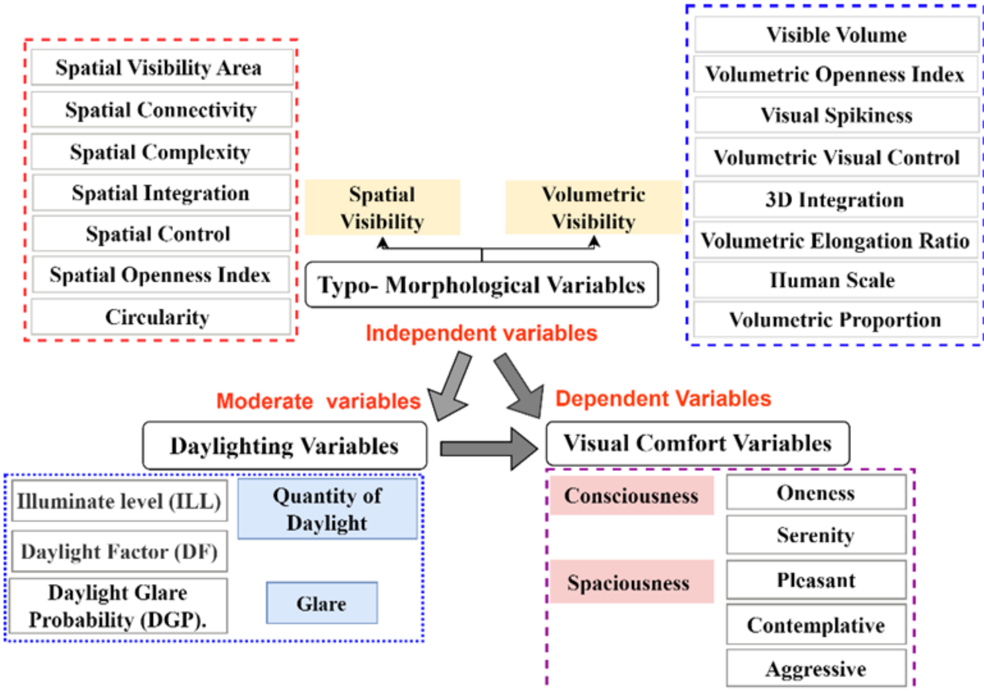


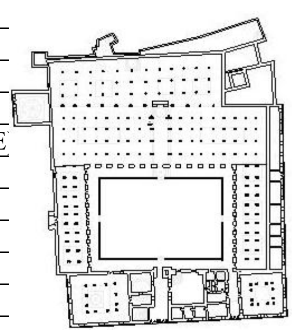
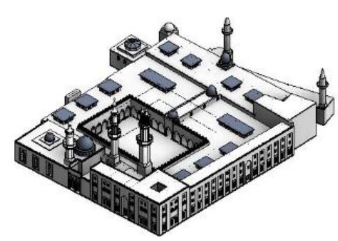
Fig.5. The study's independent and dependent variables (Researcher)

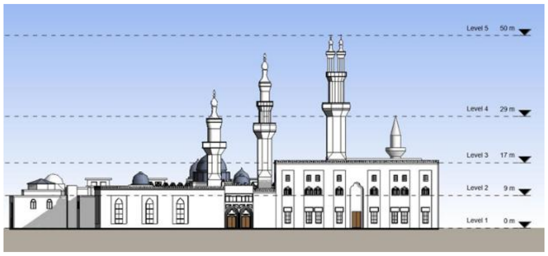
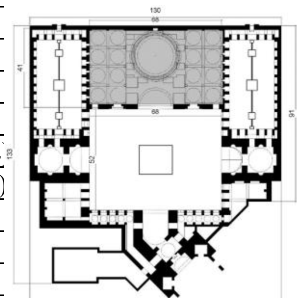
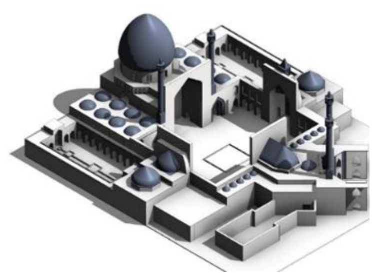
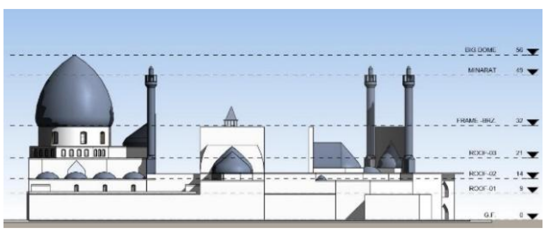
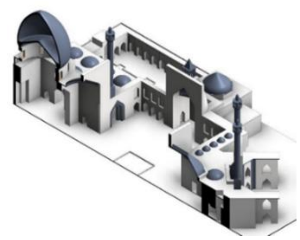
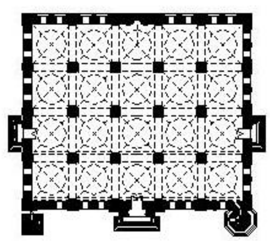
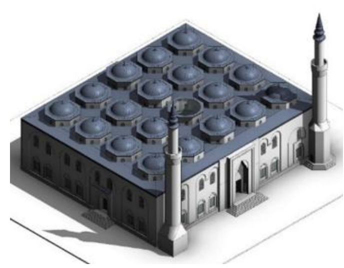
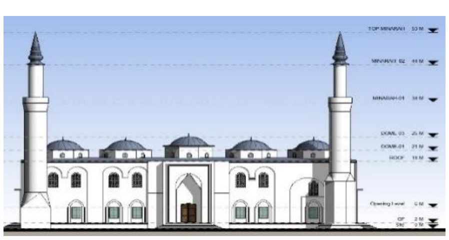
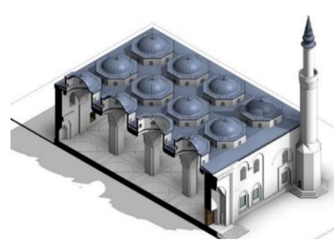
5. Research method

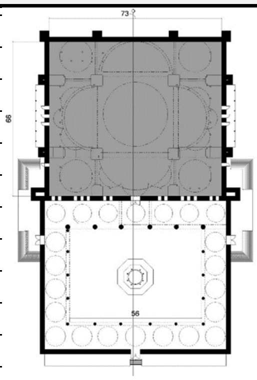
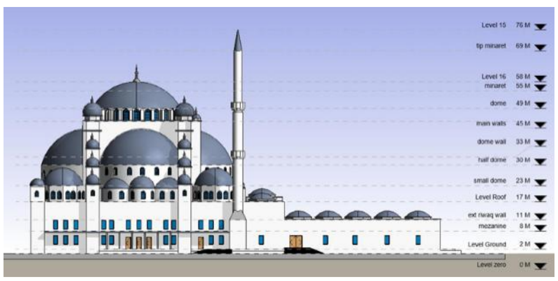
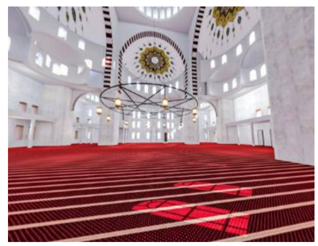
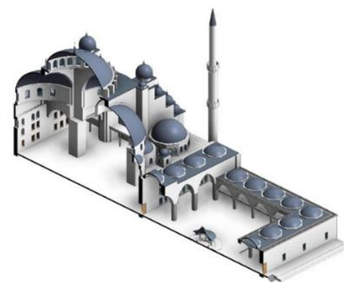
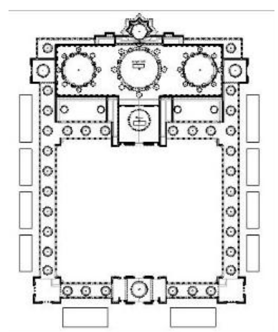
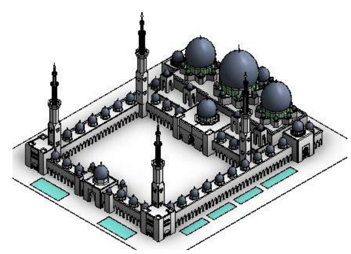
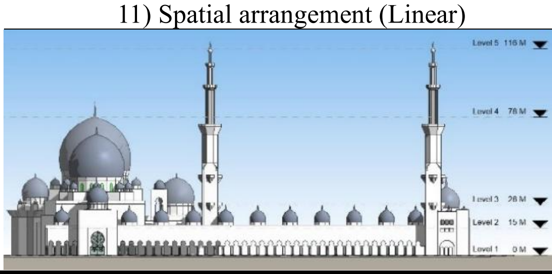
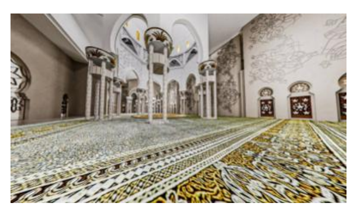
5.1 case study selection strategy

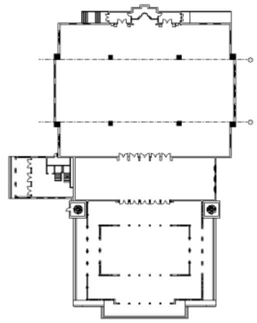
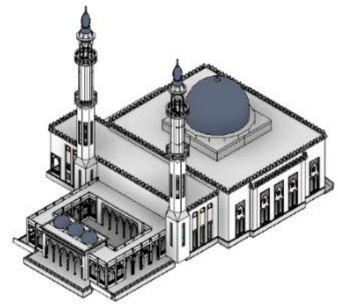
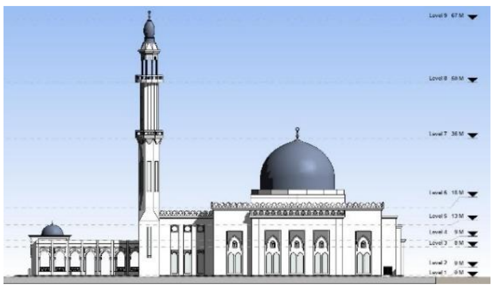
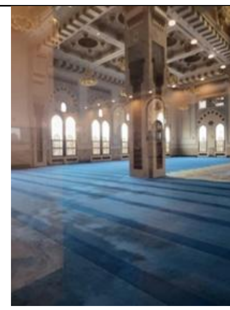
The current research is based on typo-morphological classification, integrating typological and morphological design aspects, which has led to the study of various mosque layouts. By employing categorization and matching techniques, we selected mosque syntactic and morphological patterns for investigation, comparison, and classification of the obtained prototypes. Consequently, six main mosques serve as key prototypes, as shown in Table 1.

Table 1. Names of selected mosques and classification of their morphological types (by authors)

Mosque Information/ Elevation	Mosque plan/ Internal view	Mosque top view/ internal view
Case Study #1		
1) Al-Azhar Mosque		
2) Cairo, Egypt		
3) Year of construction – 970AD		
4) Type (1) Hypostyle Pattern		
5) latitude and longitude (30.0444° N, 31.2357° E		
6) Qibla direction (138° SE)		
7) Prayer hall shape (Rectangle)		
8) prayer hall area (3700 m2)		
9) Prayer hall dimension (88m*45m*9m)		
10)No. of users (3700)		
11) Spatial arrangement (Linear)		

Mosque Information/ Elevation	Mosque plan/ Internal view	Mosque top view/ internal view
		
Case Study #2 1) Shah Mosque 2) Isfahan, Iran 3) Year of construction – 1629 AD 4) Type (2) Iwan pattern 5) latitude and longitude (30.0444° N, 31.2357° E) 6) latitude and longitude (32.6539°N, 51.6660° E) 7) Qibla direction (219.19° SE) 8) Prayer hall shape (Rectangle) 9) Prayer hall area (2750 m2) 10) Prayer hall dimension (68m*41m*32m) 11)No. of users (2750)		
		
Case Study #3 1) The Great Mosque of Bursa 2) Bursa, Turkey 3) Year of construction – 1399 AD 4) Type (3) Multiple Domed Pattern 5) latitude and longitude (40.19° N, 29.15° E) 6) Qibla direction (150.81° SE) 7) Prayer hall shape (Rectangle) 8) prayer hall area (3685 m2) 9) Prayer hall dimension (68m*56m*18m) 10)No. of users (3685) 11) Spatial arrangement (Grid)		
		

Mosque Information/ Elevation	Mosque plan/ Internal view	Mosque top view/ internal view
Case Study #4 1) Fatih Mosque 2) Istanbul, Turkey 3) Year of construction – 1463-1470 AD 4) Type (4) Central Dome Pattern 5) latitude and longitude (41.0082° N, 28.9784° E) 6) Qibla direction (151.61° SE) 7) Prayer hall shape (Rectangle) 8) prayer hall area (4800 m2) 9) Prayer hall dimension (73m*66m*58m) 10)No. of users (4800) 11) Spatial arrangement (Central)		
		
Case Study #5 1) Sheik Zayed Mosque 2) Abu Dhabi, UAE 3) Year of construction – 2007 AD 4) Type (5) Massive courtyard – triple domes 5) latitude and longitude (24.4539° N, 54.3773° E) 6) Qibla direction (258.41° SE) 7) Prayer hall shape (Rectangle) 8) prayer hall area (5880 m2) 9) Prayer hall dimension (140m*42m*78m) 10)No. of users (5880) 11) Spatial arrangement (Linear)		
		

Mosque Information/ Elevation	Mosque plan/ Internal view	Mosque top view/ internal view
Case Study #6 1) Zabeel Mosque 2) Dubai, UAE 3) Year of construction – 2012 AD 4) Type (6) Modern Pattern 5) latitude and longitude (25.2048° N, 55.2708° E) 6) Qibla direction (258.23° SE) 7) Prayer hall shape (Rectangle) 8) prayer hall area (1900 m2) 9) Prayer hall dimension (50m*38m*18m) 10)No. of users (1900) 11) Spatial arrangement (Linear)		
		

5.2 Experts Feedback Sample Size

G*Power allows researchers to estimate the required sample size for their study, given certain parameters such as effect size, desired power level, and significance level. Based on Prior analysis, one of the five types in the G*Power 3 program, the size of the experts in this study was calculated, Accordingly, 29 architects were cited as the number of expert responses. In addition, the focus of this investigation was on architects who graduated more than ten years ago.

5.3. Research Method

5.3.1. The questionnaire survey for expert feedback

The closed-end questionnaire survey for expert feedback consists of three primary components. The first part addresses the concept of spatial visibility, which includes several aspects such as the spatial visibility area, visual connectivity, complexity, integration, spatial control, openness, and circularity. In the subsequent section, the focus shifts to the concept of volumetric visibility, incorporating the visible volume, volumetric openness index, visual spikiness, visual control, human scale, volumetric proportion, and elongation. Additionally, the third component of the study encompasses daylighting, specifically examining aspects such as illuminance level, daylight factor (DF), and discomfort glare, as shown in Appendix (A).

5.3.2. Expert Feedback Using Virtual Reality (VR)

The research used Virtual Reality (VR) to achieve the best response by experts to the questionnaire survey. (VR) is a computer-generated environment with seemingly natural environments. Virtual Reali questionnaire survey headsets or helmets are used to perceive the surroundings. It provides various mediums for evaluating and interactively experiencing architectural design, and it also serves as an advanced human-computer interaction and interface tool (Fuchs, Moreau and Guitton, 2011). This study relies on the most recent techniques for virtual reality under the name (meta-quest 2) "oculus" for each case study as a support for expert feedback on the close- ends questionnaire. Quest 2 is a virtual reality (VR) headset created by Reality Labs, a Facebook, Inc. division (formerly Meta Platforms), (Fig. 6.)

Fig. 6.Meta quest 2 VR headset

This study's virtual reality creation proceeded with the following steps:

a. Building a large-scale model of the space and matching its perimeters by Autodesk Revit 2023.
b. Revit was used for building models with detail and then converting them to the 3D max for visualization
c. Selecting the materials and textures in 3ds Max and creating an environment that surrounds the model according to its location.
d. Applying daylighting value to the model at a specified time and date.
e. Adding 360-degree cameras within the model to illustrate the inside, and outside for camera shots.
f. Rendering the camera shots using (Chaos Corona 9) renderer to visualize the model that is used for 3dMax and Cinema 4D.
g. Using Adobe Photoshop 2020 to improve the 360-degree shots' colors and quality.
h. Using specialized coding and casting technologies, casting the 360-degree shoots to connect the spaces and match them with the plan.
i. Converting the virtual reality model to a link that a meta quest-2 headset or another device can readily access.
j. Data was collected by close-end questionnaire to the group of architects (Purposive sample) that graduated more than ten years ago with the aid of the virtual reality environment of each case study. Moreover, the process of gathering data from a selection of 29 experts covered a duration of around two months. Each expert requires over two days and three hours per day to provide their response. As a result, they were introduced to the virtual reality environment on the first day.

6. Results and discussion

The current study obtains the response from experts, male experts comprised 72.4% of the total, while female experts comprised 27.6%, as in Fig.7. Since most of the males in the study group attend the main prayer hall, the researchers tried to extrapolate a female-to-male gender ratio of 1/3 for the percentage of experts in the field. On the other hand, the researcher conducted interviews with 29 experts who obtained their bachelor's degrees more than ten years. In addition, they hold various levels of scientific background, including (13.8%) Assist proof in Architecture and (13.8%) PhD. Again, (24.1%) held an MSc in Architecture, (20.7%) were Ph. D students in the discipline of architecture, and (27.6%) held a BSc, as shown in Fig.8.

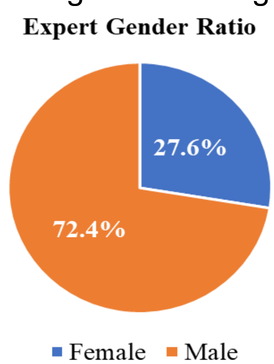


Fig.7. Experts gender ratio

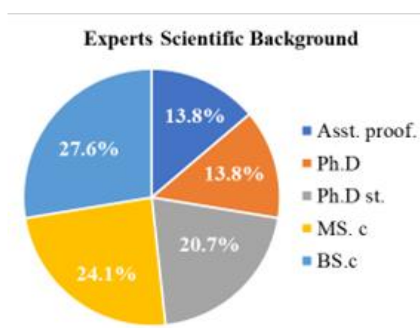


Fig.8. Expert sceintific background

ratio

6.1. Descriptive Analysis of Experts' Feedback

This section presents a comprehensive summary of the evaluations and judgments provided by the experts on a five-point Likert scale. The research here focuses on two topics: (a) expert agreement on factors in mosques and (b) expert agreement on mosques.

A. Experts' agreement on variables in the mosques: The assessment concentrates on typo-morphological characteristics, which are regarded as independent variables, including spatial visibility, volumetric visibility, and daylighting. Additionally, visual comfort is considered a dependent variable in this context. According to the data shown in Table 2, the average spatial visibility is 3.5925. Additionally, the mean value for Daylighting is 3.5057, which is second in terms of average value. In contrast, it is seen that volumetric visibility shows the lowest mean agreement value of 3.3913 among the variables covered within the context of mosques. Hence, the P-value obtained demonstrates a significant level of statistical significance, suggesting a notable difference among various categories of mosques, as seen by experts.

Table 2. One-Sample Statistics for mean of agreement on main variables regarding experts' feedback

Main Variables	N	Mean	Std. Deviation	Std. Error Mean	P. Value
Spatial Visibility	174	3.5925	0.02446	0.65870	0.000
Volumetric Visibility	174	3.3913	0.02647	0.71286	0.000
Daylighting	174	3.5057	0.03132	0.84322	0.000
Visual Comfort	174	3.4925	0.02446	0.65870	0.000

In addition, Experts preferred their agreement to spatial visibility, with a connection variable that rated first at 74.65% and Area ranking second at 73.09%. In contrast, the experience of aggression about indoor design is observed at the lowest level of agreement, suggesting that experts agreed with design elements in the inside environment of mosques. Fig. 9. illustrates experts' agreement with the variables.

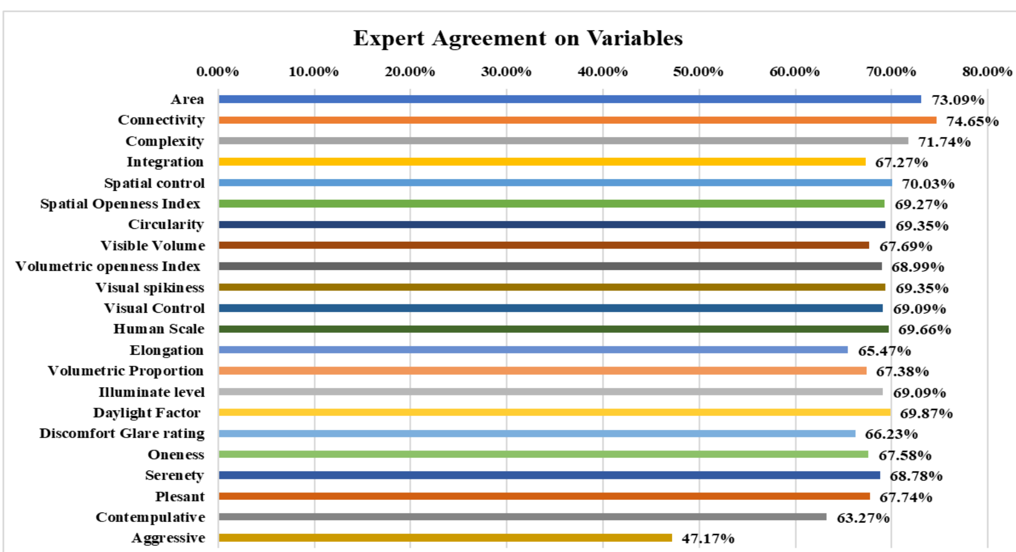


Fig. 9 Experts agreement on variables

B. Mosques Agreement Ratio

In examining the overall average of the Experts' agreement on the mosques, the Fatih mosque received (72.90%) that characterize with a central dome courtyard. Furthermore, Al- Azhar Mosque has a lower degree of agreement (64.5%) due to its flat roof with several column. In addition, as seen in Fig. 10. most mosques with a central dome, highly volumetric proportions, and minimal obstructions would have a high ratio of agreements.

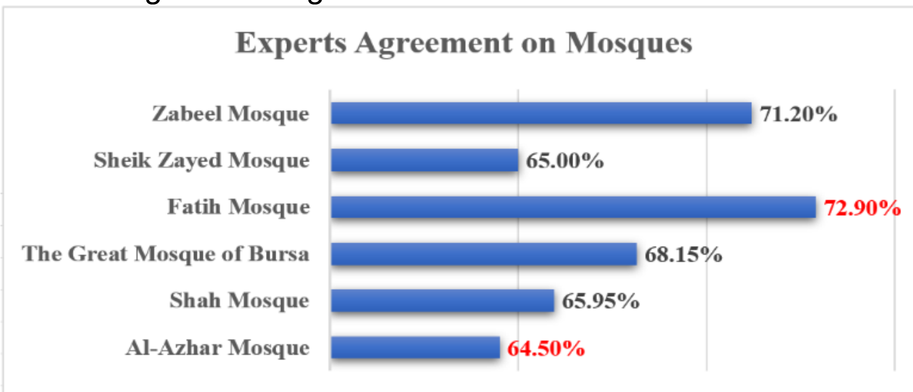


Fig. 10. Experts' agreement on mosques

6.2. Correlation Analysis

The research depends on the correlation analysis to answer the first question *(Is there a relationship between mosque building morphology and visual comfort?)*. Accordingly, Visual comfort correlates positively with all three primary parameters of mosque typo morphology. Table 3 shows that increasing spatial visibility with a value (0.570**) will increase visual comfort. Moreover, visual comfort shows an extremely substantial second-order positive relationship with volumetric visibility (0.533**). Finally, it displays a substantial positive connection with (0.425**). Furthermore, all values exhibit a significant p-value ($p<0.0000$), indicating a significant relationship.

Table 3. The correlation between main metrics according to the Expert's feedback

Typo-Morphological parameters	Correlations			
		Spatial Visibility	Volumetric Visibility	Daylighting
Spatial Visibility	Pearson Correlation	1		
	Sig. (2-tailed)			
Volumetric Visibility	Pearson Correlation	.724**	--	
	Sig. (2-tailed)	0.000		
Daylighting	Pearson Correlation	.453**	.454**	--
	Sig. (2-tailed)	0.000	0.000	
Visual Comfort	Pearson Correlation	.570**	.533**	.425**
	Sig. (2-tailed)	0.000	0.000	0.000

Fig. 11 shows that several variables within the primary parameter are positively correlated with visual comfort. Visual comfort and spatial openness index (0.473**) had the strongest positive relationship, followed by visual control (0.472**), volumetric openness index (0.444**), volumetric proportion (0.436**), daylight factor (0.433**), and area (0.414**) Remarkably, all values have a significant p-value (p<0.0000), showing that the relationship is significant.

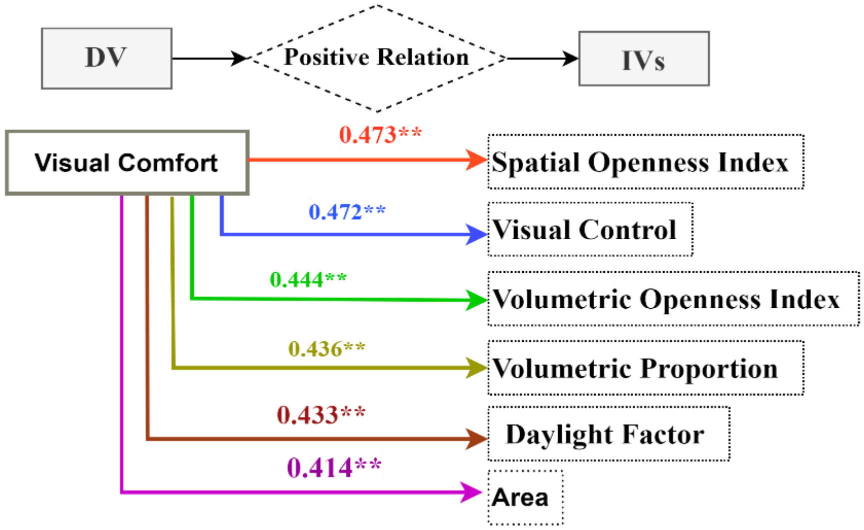


Fig. 11. Variables correlation value with visual comfort

6.3. Factor Analysis

Factor analysis was used to identify the most significant variables from the expert's opinion on mosque typo morphology which will be the answer for question two *(With the difference in typo-morphology of mosques, what are the spatial --morphological characteristics most affecting users' visual comfort inside the prayer hall?)* As a result, the KMO test analyzes whether each element expects adequate questions. The KMO of Sampling Adequacy in Table 4 is (0.889), which is extremely near to (1) indicating that factor analysis is possible. Assuming that the P-value for the Bartlett test is less than 0.01, The correlation matrix differs significantly from an identity matrix, indicating that the questions are correlated enough for factor analysis.

Table 4. KMO and Bartlett's Test to experts' feedback

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.889
Bartlett's Test of Sphericity	Approx. Chi-Square	4956.641
	df	136
	Sig.	0.000

Due to the significant variance of the variables, five components with total variances over one were created. In addition, the scree plot in Fig.12 shows that the differences between the Eigenvalues decrease and are less than (1) after the first six components.

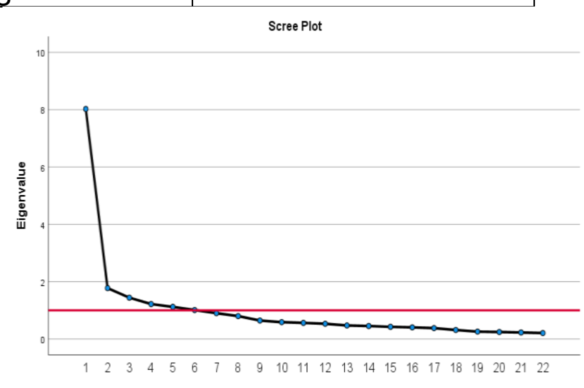


Fig. 12 scree plot of the eigenvalues of factors

Both eigenvalues and scree plots show that the twenty-two variables can be categorized and reduced into six components as shown in Table 5

Table 5. Extraction Method: Principal Component Analysis

Variables	1	2	3	4	5	Group Variables
Visible Volume	0.850					Spatial Characteristics Volumetric Characteristics
Spatial Openness Index	0.763					
Volumetric openness Index	0.747					
Spatial control	0.743					
Area - size	0.678					
Visual Control	0.596					
Elongation	0.549					
Illuminate level (ILL)		0.856				Daylighting
Daylight Factor (DF)		0.804				
Discomfort Glare		0.775				
Human Scale			0.817			Space geometry
Volumetric Proportion			0.670			
Integration				0.825		Space Articulation
Connectivity				0.752		
Visual spikiness					0.759	Space Ambiguity
Complexity					0.551	

The first component set of variables is ordered from highest to lowest weight. In group one, seven factors were ranked as the major spatial and volumetric effective variables, beginning with visible volume with an effective value of 0.850 and ending with elongation with a loading value of 0.549. Noteworthy, spatial openness index (0.763), spatial control (0.743), and area -size (0.678) are spatial variables in the first component of group variables. Others are related to space volumetric visibility characteristics, such as the volumetric openness index (0.747), visual control (0.596), and elongation (0.549).

In the second component group, three variables that are completely connected to daylighting variables are sorted. In terms of weight, illuminance level scored first with a weight value of 0.856, the daylight factor scored second with a weight value of 0.804, and discomfort glare scored third with a weight value of 0.775.

The third sorting was performed using the same grouping procedure, and it included two space volumetric visibility features, including a human scale with a loading value of 0.817 and volumetric proportion with a weight of 0.670.

Fourth sorting refers to space spatial design qualities such as integration with a weight of 0.825 and connectivity with a weight of 0.752. In the fifth and final set of sorting, two physical and visual characteristics related to space design were sorted: visual spikiness (value 0.759) and complexity (value 0.551),

Fifth categories of variables were constructed from the reported data, ranging from the most effective to the least effective in determining visual comfort in the selected mosques. Variables in volumetric visibility and spatial visibility, which together lead to the space openness, are the first effective set of variables affecting visual comfort. Daylighting comes in the second group of variables that influence visual comfort. Volumetric proportion and human scale related to building geometry are ranked third. The fourth and fifth groups primarily connect to space visual spikiness and complexity that lead to the ambiguity of the space.

Accordingly, fig.13 will illustrate more detail

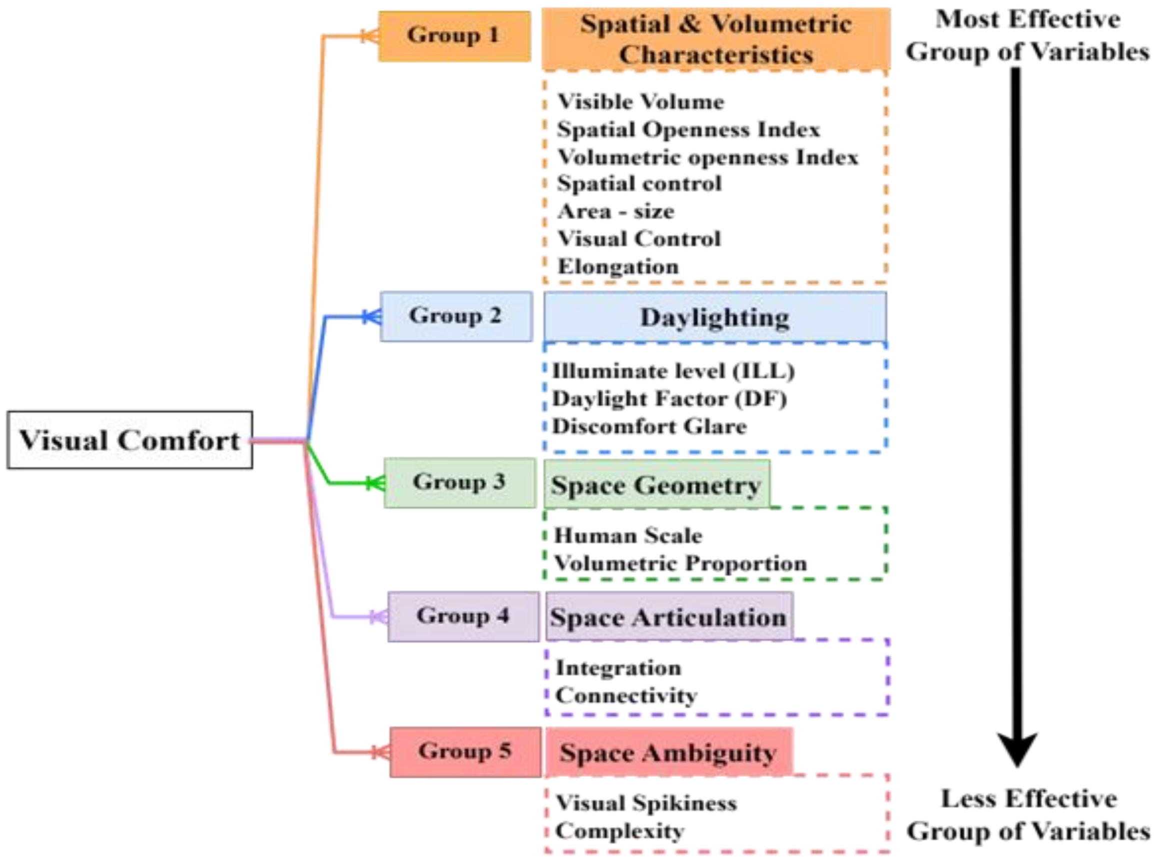


Fig. 13 Most effective group of factors

6.3. Regression Analysis

The name multiple regression refers to a model of relationships in which the response depends on two or more predictor variables. Regression analysis was used to identify the answer the question three *(To what extent do the spatial-morphological characteristics of a mosque have a causal influence on visual comfort, specifically in terms of spaciousness and consciousness?).* A response variable y may depend on a predictor variable x but after a straight-line fit. The functional form of linear regression, or linear function, is:

$$Y = B_0 + B_1 X_1 \quad (1)$$

Y= dependent variable, X= Independent variable, B0, B1 = constants or coefficients.

The process of generating a typical model by selecting **Stepwise** passes through certain stages in which it excludes all unimportant independent variables after which the functional connection remains as follows:

Analyzing the functional relationship of visual comfort as the dependent variable (Y) and all independent variables (X):

The interpretation value or adjusted R-Square is 0.421 as shown in Table 6 Since the visual comfort is 42.1 % in quantity based on the nine design characteristics achieved in the functional model. Noteworthy, the realization of this model (42.1%) could be successful research dealing with social effective, sensation, and perception.

Table 6. Visual comfort model summary

Model Summary [b]					
	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Model (8)	.654[h]	0.428	0.421	0.55601	1.552
Predictors: (Constant), Spatial Openness Index (2D), Visual Control, Integration, Daylight Factor (DF), Circularity, Human Scale, Volumetric openness Index 3D, Visual spikiness					
Dependent Variable: Visual Comfort					

The stepwise procedure was employed to exclude non-significant variables in order. After seven stages, the best typical model for Y was identified in step 8 as Model (8), which is illustrated in Table 7.

Table 7. Functional model of y "Visual Comfort"

Coefficients [a]					
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model (8)	B	St. Error	Beta		
(Constant)	0.418	0.128		3.255	0.001
Spatial Openness Index	0.086	0.027	0.121	3.180	0.002
Visual Control	0.139	0.026	0.194	5.401	0.000
Integration	0.129	0.023	0.172	5.549	0.000
Daylight Factor	0.117	0.025	0.155	4.734	0.000
Circularity	0.114	0.023	0.149	5.045	0.000
Human Scale	0.071	0.022	0.099	3.215	0.001
Volumetric openness Index	0.083	0.027	0.115	3.073	0.002
Visual spikiness	-0.056	0.018	0.089	3.034	0.002
Dependent variables: Visual comfort					

The model should be as follows:

$Y1 = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5$

Visual Comfort = 0.418 +0.088 Spatial Openness Index+ 0.139 Visual Control+ 0.129 Integration +0.117 daylighting Factor +0.114 Circularity +0.071 Human scale+0.083 Volumetric Openness Index - 0.056 Visual spikiness (4.2)

Similarly, the function indicates that visual comfort satisfaction has a direct (positive) relationship with the Spatial Openness Index, Visual Control, Integration, Daylighting Factor, Circularity, Human scale, and Volumetric Openness Index. On the other hand, it has an inverse (negative) association with visual spikiness. This means that if the visual spikiness of space increases, visual comfort will decrease.

The ANOVA results show the optimal model effects visual comfort with a degree of (1.4674E-81)—a highly significant p-value. Tests of normality find an efficient dataset with a normal distribution. Fig.14

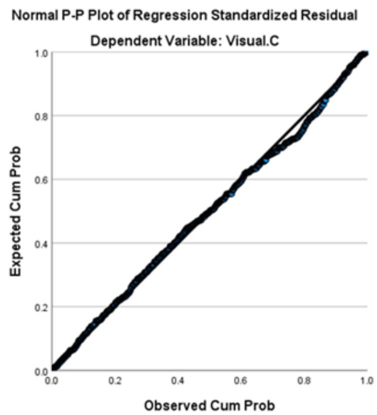


Fig. 14 Normality test of visual comfort dependence

7. Conclusion

This study sought to assess how mosque typo-morphological architecture characteristics may affect the visual comfort of worshippers by focusing on three independent variables (Spatial visibility, Volumetric visibility, and daylighting) and visual comfort as a dependent variable comprising user spaciousness and consciousness. Consequently, any change in the morphology and structure of mosques could affect how space is perceived. On the other hand, mosques have been designed in various styles and forms throughout the centuries; this research will assess the differences in visual comfort of mosques due to the different typo-morphologies of mosques by identifying the best mosque prototype in terms of visual comfort satisfaction. At length, through the mixed-methods qualitative and quantitative methods, A qualitative approach was focused on the descriptive analysis of chosen mosques via architectural drawings. Quantitative analysis of virtual reality aids the expert's response to the closed-end questionnaires. Six different typological and morphological types of mosques were chosen for the study. 29 experts were selected to complete the questionnaire using VR assistance. The current study provides answers to the research question.

The answer to the first question accomplished through the enhancement of visual comfort may be accomplished through the increase of several typo-morphological factors. The correlation analysis concluded that increased spatial openness leads to a greater perception of spaciousness and awareness. The visual control and volumetric openness index relate to the design characteristics of volumetric visibility. It has been shown that these aspects are positively correlated with feelings, psychological support, and pleasure.

The research reached the second question answer that relates to spatial-morphological characteristics most affecting users' visual comfort inside prayer halls. Five categories of variables were constructed from the reported data, ranging from the most effective to the least effective in determining visual comfort in the selected mosques. These variables involve the combination of spatial and volumetric openness, to the least influential group of variables, which primarily contribute to the ambiguity of the space. Lastly, the causal relationship between users' visual comfort and the nine design features that were satisfied in the functional model, namely (Spatial Openness Index, Visual Control, Integration, Daylighting Factor, Circularity, Human Scale, Volumetric Openness Index, and Visual Spikiness) as a response to the research third question.

The study concluded that an attractive spatial volume can be realized in a mosque design including a central domed ceiling devoid of obstacles and limitations. Mosque typologies with obstructions in their primary prayer rooms, such as hypostyle mosques, have diminished visible volume due to hurdles and barriers that create visual spikiness, resulting in a lower openness score. The square configuration of the prayer hall, with a central dome, offers enhanced visual control, as the entirety of the visible space can be observed from various perspectives, contributing to an organized arrangement and a high level of visual comfort for users. If the 3D visual volume truly represents spatial openness, does an increased 3D visual volume correlate with enhanced visual comfort? This study will introduce a novel concept that expands opportunities for future research.

Thus, the square design of the prayer hall, having a central dome, enhances visual consistency. A significant portion of the visual area is observable from multiple perspectives within the overall configuration, providing users with an enhanced sense of visual comfort. Ultimately, the current study recommends further study on the impact of sociocultural factors on the morphological transformation of mosques. Scholars may also do a comprehensive investigation and analysis to develop a novel classification system for mosques, using criteria such as the shape and design of the courtyard and its impact on the overall layout configuration of the mosque.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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