European Journal of Science and Theology, August 2026, Vol.22, No.4, 1-34

ARCHITECTURAL VISUAL DESIGN ARCHITECTURE OF PRAYER: AN EYE-TRACKING STUDY OF CHURCH ALTARS AND PRAYER SPACES - INFLUENCE ON CONCENTRATION AND MEDITATION – DESIGN GUIDELINES

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(Received 14 May 2026, revised 30 July 2026)

Abstract

In architectural design, there is a continual search for the most effective functional and stylistic solutions. Adapting space to the user, that is, the personalisation of space, constitutes one of the most important aspects of contemporary design process models. This is of particularly great significance in the case of religious buildings, in which appropriate design solutions are sought in order to enhance the sense of safety and to create conditions conducive to concentration, prayer, and meditation. Such buildings are designed with the utmost care and with sensitivity to the aesthetic and emotional perception of their future users. In pursuing the most appropriate architectural solutions for facilities of this kind, eye-tracking analyses of graphic visualisations are employed. The results obtained reveal previously unidentified findings of considerable practical relevance for the design of sacred and meditative interiors. Spaces incorporating natural lighting, soft textile furnishings, low seating elements, and plant-based features were consistently evaluated as the most calming, safe, and conducive to contemplative practice, and simultaneously generated moderate, positive autonomic arousal responses. Conversely, enclosed, austere interiors with limited natural light and no greenery produced the strongest physiological tension alongside the lowest subjective ratings, indicating negative emotional valence. The integration of eye-tracking metrics with pupillometric data and self-report measures demonstrated that high autonomic arousal may reflect either positive aesthetic engagement or discomfort depending on the spatial qualities of the interior – a distinction that neither physiological nor subjective measures alone could establish. The only statistically significant correlation between objective and subjective measures indicated that spaces perceived as most suitable for prayer and meditation generated the weakest autonomic responses, confirming that successful sacred architecture operates through calm rather than stimulation. These findings provide evidence-based guidelines for the design of

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interiors intended for spiritual practice and offer a replicable methodological framework for the affective evaluation of architectural spaces.
Keywords: calming spaces, spaces conducive to prayer meditation, church design, soothing interiors, neuroarchitecture design guidelines, eye tracking

1. Introduction

The influence of architecture on the human emotional state is becoming increasingly widely recognised and is being subjected to analytical examination. The impact of architectural form, scale, colour scheme, and style may exert a tangible effect on people's well-being and may indirectly generate subjective sensations associated with one's condition at a given moment [1]. In order to identify the relevant factors that genuinely affect human beings, a range of research methods is employed to enable the investigation of architecture's influence. The possibility of identifying the individual elements that affect well-being may significantly transform the very definition of architectural design [2]. This is particularly important in buildings and spaces intended for sensitive social groups, both in terms of age and level of disability.

At present, in the preparation of design documentation, particular attention is paid to the aspect of architectural creation, especially in buildings with a specific function, such as therapeutic centres, homes for older persons, kindergartens and schools for children with disabilities, as well as other healthcare facilities. The scale of a building, its colour palette, functional layout, and spatial solutions may influence user perception either positively or negatively [3]. Many of these aspects form part of universal design, grounded in the principles of architectural composition, which make it possible to develop the most optimal solutions for the broadest possible group of potential users [4]. At the same time, numerous cognitive technologies make it possible to conduct experimental analyses through the virtual presentation of design solutions to real participants who, after engaging with digital material, evaluate such solutions in a subjective manner. One such solution is eye tracking, a technology which, by measuring the points at which users direct their gaze, makes it possible to identify areas of interest, the number of fixations, and the potential reception of an interior space [5].

This paper presents the process and results of a perceptual and emotional experiment employing eye-tracking technology to evaluate twelve AI-generated architectural visualisations of interiors designed for prayer and contemplation. The stylistic character and spatial qualities of the interiors were generated with the aid of artificial intelligence and maintained within an adopted design convention [6]. The experiment examined participants' visual attention and emotional responses using three complementary measures: fixation duration, fixation count, and pupil diameter as a physiological indicator of autonomic arousal. Subjective evaluations were additionally collected through a three-item questionnaire administered after each visualisation. The results were analysed statistically and interpreted in relation to specific architectural features of the presented spaces, with the aim of identifying design elements that contribute to a sense of calm, safety, and suitability for contemplative practice.

Whenever preparing an architectural design, the architect seeks the best possible answer to questions concerning the attainment of high-quality space. The pursuit of an appropriate outcome in this regard is based primarily on experience and personal intuition [7]. The evaluation of such efforts may be supported by public consultations, questionnaires, conversations with potential users, or other direct forms of contact. It is worth noting, however, the possibilities offered by digital verification of design development through the use of augmented and virtual reality. During the verification of design assumptions and outcomes, there is an effort to identify as many different factors as possible that influence the perception of the interior. The eye-tracking method enables highly precise examination of individual areas and points within interior visualisation graphics, which may in turn facilitate the identification of specific zones affecting the user's sense of well-being.

2. The design process model and contemporary design tendencies

Among the numerous research methods used to analyse the perception of space, eye tracking occupies a prominent position. It is a non-invasive method that makes it possible to obtain highly precise and high-quality results in experimental studies [8]. Within research on neuroarchitecture, this method is frequently identified as the most effective and the most accurate. Three principal modes of measuring the eye's response to a presented or displayed space may be distinguished: screen-based tracking, augmented-reality glasses, and portable eye-tracking glasses. For the purposes of the present study, a monitor-based system was selected as the most accurate research method.

From the perspective of architectural design, the creation of digital twin models for volumetric buildings is of considerable importance [9]. This is particularly significant because it enables the quality of a designed space to be assessed even before its construction. The introduction of analytical methods for studying spatial perception may take place either during the design process itself or at the final stage of design, immediately prior to construction [10]. At each of these phases, architectural modifications remain possible in such a way as to enhance the level of perception and reception of the designed space by its future users. For this purpose, it is possible to employ a traditional 3D model of the building, prepared as a spatial representation of the proposed architectural object. It is also possible to use BIM technology, which allows a substantial amount of data to be assigned to individual elements, thereby resulting in an even higher quality of the findings obtained [11].

From the point of view of ESG policy and building certification systems, for example the LEED and BREEAM standards, appropriate and conscious design with due attention to the quality of space is of major importance [12]. The efficiency and standard of a building do not depend solely on its physical parameters and technological solutions, but also on its function and its capacity for adaptation over subsequent years of use. An equally important element is the development of personalised architectural solutions dedicated precisely to the appropriate group of future building users.

Among the technologies associated with augmented reality and eye-tracking analyses, it is also possible to generate 3D models on the basis of scans of existing buildings [13]. In projects of this kind, which are more complex in terms of implementation, design principles associated with neuroarchitecture appear to be crucial to the achievement of a successful investment outcome.

Research into the quality of space and the perception of architecture may be related not only to buildings and architectural elements, but also to the psychological reception of urban spaces within cities [14].

For the proper execution of an experiment on architectural spaces using eye-tracking technology, a key aspect and indeed the core of the study lies in the visualisations presented to the participants. In order to select such materials optimally and to determine precisely what they should contain, extensive architectural knowledge and professional experience are required [15]. However, given the vast number of possible design solutions, styles, colours, forms, and furnishing elements, the knowledge and skills of a single individual may prove insufficient. In order to improve this process and to prepare the visualisations in the best possible manner and at the highest attainable level, the use of artificial intelligence is fully justified. The proper application of AI tools means that the architect's knowledge and experience are supplemented and systematised through the computational resources of a given artificial intelligence model [16]. In terms of the speed of data analysis and the ability to generate diverse combinations, AI models constitute a solution that significantly accelerates the work of architectural designers. For this reason, particularly at the conceptual design stage, it is worth drawing upon the capabilities of this type of technology in order to create still better architecture, spaces, urban environments, and also sacred buildings.

There is a continuing search for the most appropriate solutions in the field of architectural form and the colour composition of interiors. An important aspect of this process is the need to recognise the historical background to changes in design styles over time. Noticeable trends and design directions can be identified that may be regarded as global, that is, as reflecting the aesthetic preferences and perceptions of the statistically largest group of people [17]. These modifications in architectural style and its constituent elements should be treated as a point of departure for research. For some reason, there is a discernible tendency for the visual and aesthetic preferences of successive generations to change. This may be associated with the widespread and unrestricted flow of information and inspiration through the internet and social media. At present, it takes only a moment to present to other users anywhere in the world the interior of one's flat, house, or office. Such a free and global exchange of inspiration and aesthetic experience leads to the rapid worldwide dissemination of particular stylistic trends [18]. The very high speed with which a given architectural solution spreads across the world has beneficial effects in terms of information exchange. On the other hand, local and individual solutions associated with culture, the history of a place, and a given community appear to be increasingly blurred by global trends, which do not arise from a particular place but are rather products of the internet-based exchange of ideas. It is therefore worth investigating why certain architectural solutions enjoy such popularity, while others disappear among the billions of publications disseminated through social media. Eye-tracking technology offers assistance in the assessment of this phenomenon by enabling a closer understanding of the user's perception of space.

In order to address the above questions efficiently and purposefully, it is necessary to examine the human brain more closely and to focus on research in neuroscience [19]. This is important insofar as it may lead to an explanation of why the human brain directs individuals towards the choice of particular architectural solutions and forms rather than others. Why do some design trends appeal to a considerable number of users, while others do so to a lesser extent, or not at all? Why does this occur? Making choices of this kind is connected with human nature and with the instinctive manner in which design-related decisions are made [20].

An indicator of spatial quality may also be considered in relation to the concept of well-being and the corresponding level of user satisfaction. In this respect, the personalisation of users' space, tailored directly to their needs, requirements, and stylistic preferences, is of particular importance. For the rapid and accurate verification of the level of such perception, eye-tracking technology once again appears to be the most effective solution [21]. This type of approach, namely the individualisation of the interior space of a designed building in relation to its actual future users, is identified as the most purposeful. This follows from the fact that such a process transcends social differences arising from geographical location, culture, history, and similar determinants.

An important factor that is increasingly being taken into account in architectural design is the ideology associated with biophilic design and ESG. However, the introduction of any concept in this field requires its confrontation with the future users of the building. Analyses undertaken in this respect may assist in selecting the most purposeful and preferred solutions in the area of ecological technologies and the incorporation of plants within buildings. Without appropriate analysis supported by virtual tools, it is not possible to present a variety of proposals and, consequently, to select the most suitable one.

The development of an analytical model of architectural design may prove to be the key to raising the quality of architecture to a level significantly higher than that currently practised [22]. At present, the model functions in such a way that users' opinions of a building can be identified only after the building has been completed and has been in operation for some time. This is manifested through the time spent by users in a given building and their subsequent evaluation of the adopted design solutions [23]. Breaking with this model consists in enabling an actual interaction between architecture and users already at the design stage through virtual visualisation tools (Figure 1). Conclusions generated during the design phase may still be implemented within that same phase, and the architectural object itself may thereby be even more closely adapted to the actual needs and preferences of its users.

2.1. Design assumptions and the problematic framework of the issue

During the design of a building and its architecture, the lead architect is invariably confronted with a major professional challenge. This consists in formulating a response to the design brief in the form of design documentation and, subsequently, in the form of a physical building object. The considerable responsibility resting upon the architect is reflected in numerous attempts to test the concepts being developed [24].

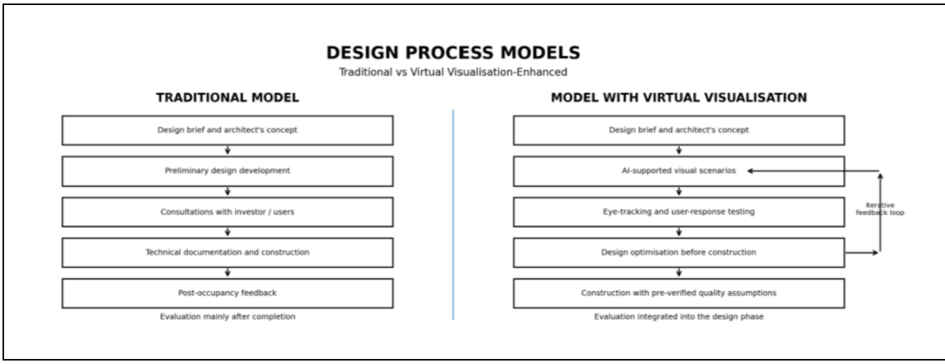

Figure 1. Comparison of two architectural design process models: the traditional model, in which the evaluation of spatial quality is undertaken primarily after project completion, and the model enhanced by virtual visualisation, in which AI-supported visual scenarios, eye-tracking analysis, and user-response testing are incorporated into the design phase, thereby enabling iterative optimisation before construction.

Among the conventional methods used to verify the suitability of architectural solutions are public consultations, multimedia presentations, as well as discussions and meetings with investors and future users. These are, however, methods that still require the lead architect to rely to a significant extent on personal intuition and experience. What is lacking in the above conventional methods is hard data and a substantive verification of design solutions.

At present, the possibilities for presenting an architectural design are highly advanced. Visualisations and animations can be rendered with an almost photorealistic effect. This means that the possibilities of the graphic representation of an architectural design make it possible to present it in a manner closely resembling a photograph of an already existing building [25]. Artificial intelligence should also be included within this group of tools, as it makes it possible to generate an even greater number of variations on the architect's initial concept.

On the basis of findings from previously conducted studies, certain tendencies in user behaviour were identified. These concern visual composition, which significantly affects the location of fixations. Areas and ranges of chromatic forms were also specified that appear to be neutral in terms of attracting visual attention and generating a large number of fixations [26]. The knowledge and conclusions formulated on the basis of previous research were used in carrying out the experiment described in this article.

To date, the eye-tracking analysis method has made it possible to present genuinely designed architecture to physical and real users, that is, to human participants. This is a key element of the experiment, which does not rely on the use of an algorithm or application to assess the quality of sacred interior architecture; rather, the evaluations are provided by individuals who physically and directly participate in the study.

For this reason, the results obtained are so unique and distinctive, since they were derived from real participants who, in their own individual manner, engaged with the graphic representation of the designed architecture.

The study is intended to promote this model of the design process and to demonstrate its distinctive form, which makes it possible to obtain the impressions and opinions of future users of a building even before its actual construction [27].

3. Experiment: eye-tracking research on the interiors of sacred buildings generated using artificial intelligence tools

On the basis of the results obtained in previously conducted experiments, a set of design assumptions was formulated and subsequently applied in the procedure for developing the interior designs. Twelve visualisations were selected, differentiated in terms of stylistic variety, compositional framing, and the time required to complete the experiment (Figures 2-13). Drawing on experience from earlier experiments, it was observed that a set of twelve visualisations constitutes an optimal number at which the participant does not yet display fatigue or boredom in relation to the experimental procedure [28]. It was also necessary to introduce an interlude between the displayed images, enabling rest and a certain form of visual reset. For each visualisation, an individual point was selected whose purpose was to direct visual attention towards an area that was visually neutral. This area was chosen subjectively on the basis of the absence of details or elements that might potentially attract the participant's gaze. Based on the knowledge and experience derived from previous experiments, a clear tendency was observed for participants to focus on precisely such visually engaging elements [29]. It was also noted that participants generally concentrated on the central part of the visualisation, which is a natural feature of visual observation, particularly in relation to spaces of this kind. In order to prevent distortion of the fixation results, specially designed graphics were prepared with a marked point intended to direct the participant's gaze towards a potentially non-attractive location. A red dot on a black background, displayed immediately before the presentation of the target image, was introduced in order to relieve the eyes from their natural tendency to focus on the centre of the visualisation. This procedure was intended to improve the results and to provide an even more accurate understanding of the emotional properties of the visualisations presented [30].

The subject matter of the visualisations was deliberately narrowed to a specific type of space which, in itself, possesses numerous attributes inherently associated with it. This constituted a deliberate measure aimed at verifying precisely defined emotions and the influence of architecture on their intensity. The interiors of sacred places depicting the inside of a temple or chapel are characterised by qualities unique to this category of interiors [31]. This is due to the fact that a place intended for religious worship is governed by a certain etiquette of human behaviour that remains relatively constant and comparable regardless of the geographical location of the building. The emotional properties of such places are associated with religious worship and with the elevation of the building's status through its consecration. Such buildings are exceptional in many respects, and only in their case does there exist a customary mode of behaviour that is encountered at a comparable level in no other type of building [32]. For these reasons, it was decided to focus the scope of the experiment precisely on this category of architectural objects.

With such a point of departure for conducting the experiment, it appears possible to obtain a relatively precise and reliable indicator for the responses provided by the participants to the questions displayed after each visualisation.

It is assumed that each participant is capable, at least at a basic level, of identifying space and architecture. It is also assumed that each participant is able to recall emotions associated with being present in a space of this kind and to remember the general atmosphere accompanying such interiors [33]. For these reasons as well, the choice of architecture and the type of interior appears to be particularly purposeful for the study.

Figure 2. Image 1 (V01), visual representation of religious, meditation space - generated in AI.

Figure 3. Image 2 (V02), visual representation of religious, meditation space - generated in AI.

Figure 4. Image 3 (V03), visual representation of religious, meditation space - generated in AI.

Figure 5. Image 4 (V04), visual representation of religious, meditation space - generated in AI.

Figure 6. Image 5 (V05), visual representation of religious, meditation space - generated in AI.

Figure 7. Image 6 (V06), visual representation of religious, meditation space - generated in AI.

Figure 8. Image 7 (V07), visual representation of religious, meditation space - generated in AI.

Figure 9. Image 8 (V08), visual representation of religious, meditation space - generated in AI.

Figure 10. Image 9 (V09), visual representation of religious, meditation space - generated in AI.

Figure 11. Image 10 (V10), visual representation of religious, meditation space - generated in AI.

Figure 12. Image 11 (V11), visual representation of religious, meditation space - generated in AI.

Figure 13. Image 12 (V12), visual representation of religious, meditation space - generated in AI.

The assumptions concerning the emotional responses associated with the twelve visualisations are regarded as constant and broadly comparable for each participant. Within this methodology, it is assumed with a high degree of probability that each participant will associate this type of space primarily with positive emotions. This assumption is independent of subjective views on religious matters, since the experiment does not evaluate religion or the Church as such, but rather space and architecture, that is, the material and physical sphere which makes concentration on worship possible. For these reasons, it is assumed that each participant associates such spaces with positive emotions, a sense of safety, silence, the absence of an excessive number of auditory and visual stimuli, a limited amount of light, intimacy, solemnity, respect, and the possibility of rest and relaxation. Emotions and states of well-being of this kind usually accompany the moment when one enters a temple from the external space of a street, square, or courtyard. Passing through the door and closing it behind oneself results in entry into a space in which the stimuli acting upon a person from the outside are extinguished, and one begins to dwell in the calm atmosphere of a quiet and dignified interior. Religious buildings are saturated with symbolism associated with the Bible [34]. The passage through the door from the outside world into an enclosed and sacred space may also be understood as a symbolic transition into a familiar and tranquil world, free from noise, commotion, and the rush of life. Upon entering a temple or chapel, one begins to inhabit a space intended to calm the human being and to foster the highest possible degree of concentration on meditation, prayer, and conversation with God.

The above set of design and experimental assumptions is intended to confront them with the actual perception of space by the participants in the experiment. This constitutes the principal aim of the study: to determine whether there are any elements of space that may be considered, in overall terms, better or worse with regard to enabling that space to fulfil its primary function, namely to facilitate meditation and prayer [35]. Through the statistical evaluation of the recorded points of visual fixation and the responses to the questionnaire, the authors of the experiment seek to formulate conclusions concerning the influence of architecture on the level of spatial quality.

On the basis of previous experiments and the findings of other researchers, it is assumed that architecture may exert a significant influence on the quality of space and on its intended purpose. A design question that still remains unresolved is the identification of the actual factors, details, colours, and architectural forms that possess a real capacity to induce positive or negative emotional states in human beings. The identification of these elements could bring about a significant breakthrough in architectural design.

Many outstanding examples of sacred architecture have emerged from design assumptions based primarily on experience and design intuition. Only rarely are digital possibilities employed that confront the architectural vision with the potential perception of space [36]. Owing to the advanced capabilities of augmented reality, research apparatus, and artificial intelligence tools, it is now possible to conduct a range of important studies and make significant discoveries concerning the emotional influence of architecture on the human psychophysical state. In summary, if contemporary technology enables an in-depth understanding of the relationship between architecture and the human being, it is worth making use of these possibilities in order to raise the design standard of future architectural projects. The visualisations were created on the basis of a carefully planned and detailed description of the interior, its character, dimensions, colour scheme, and function. The only technology used to create the visualisations was the ChatGPT platform, version 5.4. In the present study, no other task was carried out with the use of artificial intelligence beyond the generation of twelve visualisations of church or chapel interiors. ChatGPT-based technology had also been employed in previous experiments, in which similar graphic representations were created with its assistance. This offers a remarkable opportunity to obtain graphic data through the introduction of appropriately formulated guidelines. The effects of these actions proved satisfactory. Expectations regarding graphic quality and representational fidelity were met to a satisfactory degree, and in this form the generated materials could be used for research purposes.

With regard to the descriptive guidelines that were introduced, the following descriptions were used as prompts generating the final visualisations.

They were as follows:

“Generate a space of a soothing character, conducive to meditation, which will serve as an example of the interior of a Catholic church; the architectural style and the age of the church are of no importance, as the principal concern is the character of the space.”

“Create an image depicting a room designed in such a way as to promote human well-being, tranquillity, and mental concentration, and to enable, in silence and calm, the discovery of a way to focus, for example, on prayer. Select the scale of the room, the architectural form, the colour scheme, and the amount of light accordingly. This should be a view of the altar of a Catholic church with modern and contemporary architecture.”

“With regard to the visibility of other people in the interior, including worshippers, it is left to your discretion whether their presence may enhance prayerful concentration or, conversely, contribute to distraction.”

“The view of the space should be directed towards the altar. The arrangement and perspective are optional. The visualisation should be realistic, with the viewing direction corresponding to the eye level of a human observer.”

“The image format should be horizontal, with dimensions of 1920 pixels by 1080 pixels. Apply a subdued colour palette maintained in shades of grey.”

Through such descriptions of expectations concerning the space and its quality, a wide range of visualisations was obtained, from which twelve were ultimately selected in accordance with the assumed duration of the study involving participants.

The AI tool ChatGPT facilitates the creation of images in the expected form within a short period of time and with the possibility of producing numerous variants and modifications. This constitutes an invaluable opportunity to generate a substantial amount of material and to compare it in order to select the most suitable examples for research purposes.

The scope of the experiment was further expanded through the inclusion of questions posed to the participants, which were displayed after each visualisation [37]. The collection of responses to the questions formulated below constituted an attempt to obtain even more precise experimental results and to provide an answer to the stated research thesis.

Three questions were formulated using a five-point response scale. Responses were recorded by clicking on the appropriate scale parameter ranging from -2 to 2. The survey questions were as follows:

Can the presented space be described as calm and soothing?
Response scale: 5-point Likert (1 = strongly disagree, 5 = strongly agree)
Is the presented space suitable for meditation, concentration, or prayer?
Response scale: 5-point Likert (1 = strongly disagree, 5 = strongly agree)
Do you feel safe and comfortable in such a space?
Response scale: 5-point Likert (1 = strongly disagree, 5 = strongly agree)

An experiment prepared in this way makes it possible to examine multiple issues simultaneously. Above all, it constitutes an attempt to answer the research thesis, namely whether, and in what manner, architecture may influence positive and negative emotions. At the same time, data were also obtained that made it possible to verify how accurately artificial intelligence, through the generation of interior visualisations, enabled the creation of calm and soothing architectural spaces.

The testing of new technologies and the integration of computer science with architectural engineering make it possible to obtain multidisciplinary research results [38]. When analysed appropriately from a statistical perspective, such data lead to conclusions concerning the quality of space and its perception by the participants involved in the study.

There is no doubt that information technologies associated with artificial intelligence and eye tracking are raising the level of scientific research to a higher, and as yet not fully defined, mode of analysing the perception of space. The possibilities of understanding space and its influence on users may lead to far better outcomes in architectural design, achieved not solely through the architect's experience and intuition, but also through knowledge grounded in scientific results.

In order to obtain comparable impressions and comparable results from the analysis of the participants' gaze fixations, it was decided to maintain similar characteristics across the spaces shown in the visualisations. For this reason, no substantial differences were introduced in terms of spatial scale, colour scheme, visual reception, or overall chromatic composition [39]. The twelve visualisations differ from one another, but only to a limited extent. This procedure was deliberate and was intended to produce even more precise research results.

4. Methodology – eye tracking. description of the apparatus, research method, and experiment.

The study employed eye-tracking technology combined with pupillometric measurement and subjective self-report to analyse visual attention patterns and emotional responses to twelve AI-generated visualisations of architectural interiors designed for prayer and contemplation. Data were collected using the stationary Tobii TX300 (Tobii AB, Sweden), a binocular, video-based system operating in the near-infrared spectrum and based on the dark pupil and corneal reflection method.

The device records eye movements at a sampling rate of 300 Hz (every 3 ms), providing high temporal resolution. Its spatial accuracy ranges from 0.4° to 0.9°, with precision between 0.04° and 0.15°, depending on lighting conditions and gaze angle. The system allows for natural head movement without stabilisation within a tracking area of 37 × 17 cm, with an optimal viewing distance of approximately 65 cm.

Stimuli were displayed on a 23-inch TFT monitor (1920 × 1080 pixels) integrated with the eye tracker. The setup was connected to an Asus G750JX-T4191H laptop (Intel Core i7-4700HQ, 8 GB RAM) running Windows 10 and Tobii Studio 3.3.2 (Tobii AB, Sweden). Participants were seated at a distance of 65–75 cm from the device.

The experiment was conducted in a controlled laboratory at the Department of Computer Science, within the Centre for Innovation and Advanced Technologies at Lublin University of Technology. The room was acoustically isolated and illuminated with artificial light to ensure stable recording conditions. Each session involved only the participant and a moderator supervising the procedure.

Before the experiment, participants provided informed written consent and received instructions regarding the procedure. Both the research procedure and the documentation received a positive opinion from the Ethics Committee for Scientific Research of the Lublin University of Technology No. 1/2024 of February 19, 2024.

After collecting sociodemographic data, a standard nine-point calibration was performed to ensure accurate gaze estimation. Participants were asked to remain relatively still and to focus on the presented stimuli.

The experimental procedure consisted of 12 trials, each corresponding to a visualisation of an architectural interior. Each trial began with a 1-second fixation phase, during which a red circular marker (5 mm in diameter) was displayed at a predefined location specific to each stimulus, ensuring a controlled starting point of gaze. This was followed by a 300 ms blank screen to reset attention and stabilise eye position. The stimulus was then presented for 8 seconds, during which participants freely viewed the image without any assigned task. After each stimulus, participants completed a short questionnaire comprising three items rated on a 5-point Likert scale, designed to capture subjective evaluations of the observed space. The entire sequence – fixation point, blank screen, stimulus presentation, and questionnaire – was presented automatically.

As a result of the study, 65 individual recording sessions were obtained, each comprising dynamic visualisations of the presented interiors with an overlaid gaze cursor indicating the participant's point of regard over time. Aggregated eye-tracking data from all participants enabled the generation of several complementary forms of visual analysis, including heat maps, gaze opacity maps, and scan paths. These visualisation techniques present data directly on the analysed stimuli, thereby reducing cognitive load and facilitating intuitive interpretation.

Heat maps illustrate the distribution and intensity of visual attention using a colour scale, where warmer colours indicate areas that attracted longer or more frequent fixations. They are typically based on cumulative fixation counts or fixation durations across all participants and are particularly useful in studies involving free viewing, as in the present experiment. The heat maps presented in Figures 18–29 were normalised to a 0–40 scale based on fixation counts in order to ensure comparability across stimuli and participants. This normalisation reduces the influence of differences in the total number of fixations and allows for a clearer representation of the relative distribution of visual attention rather than absolute fixation density. The legend for the presented heat maps is shown in Figure 14.

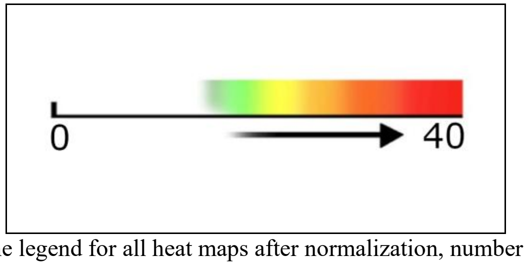

Figure 14. The legend for all heat maps after normalization, number of fixations.

In contrast, gaze opacity maps provide an inverse representation of attention distribution, typically using grayscale values. Areas that were observed by participants remain visible, while regions that did not attract attention are progressively obscured. This form of visualisation highlights only those parts of the stimulus that were actually explored, offering an alternative perspective on visual engagement.

Three quantitative eye-tracking metrics were selected for statistical analysis: fixation duration (FD), fixation count (FC), and pupil diameter. Fixation duration reflects the mean length of time the gaze dwells and serves as an indirect indicator of cognitive effort and affective engagement. Fixation count captures the total number of fixations, providing a measure of the intensity and persistence of visual engagement. Pupil diameter, averaged across both eyes, constitutes the only physiologically direct measure of emotional arousal among the metrics employed, as its variation is controlled by the autonomic nervous system independently of voluntary gaze behaviour.

Data quality was assessed prior to analysis. Only recordings in which the eye tracker maintained valid gaze data for at least 80% of the stimulus presentation time were included in the analyses, yielding between 52 and 56 valid participants per visualisation. Recording Rec 35 was excluded from all analyses due to the absence of valid data across all conditions.

Fixation duration and fixation count were extracted from Tobii Studio as mean values, defined separately for each of the 12 visualisations. Outliers were identified and removed using the interquartile range method (±1.5 × IQR) prior to computing descriptive statistics and inferential tests.

Pupil diameter was computed as the mean of left and right eye measurements for each one-second interval of stimulus exposure. To control for luminance differences between visualisations, the first second of each stimulus (Sec 1, t = 1 s) was used as the within-stimulus baseline. The magnitude of the autonomic response was expressed as the absolute percentage change from this baseline: |% change| = |Sec N − Sec 1| / Sec 1 × 100. This approach eliminates the confounding effect of the pupillary light reflex on between-visualisation comparisons.

In addition to the eye-tracking measures, participants completed a short questionnaire after viewing each visualisation. The questionnaire comprised three items rated on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), designed to capture distinct dimensions of the subjective emotional response to the presented spaces: (1) perceived calming quality ("Can the presented space be described as calm and soothing?"), (2) perceived suitability for contemplative practice ("Is the presented space suitable for meditation, concentration, or prayer?"), and (3) perceived safety and comfort ("Do you feel safe and comfortable in such a space?"). The three items were analysed separately to preserve the specificity of each evaluative dimension, as they address qualitatively distinct aspects of the affective response to architectural space.

Statistical analyses were conducted in Python 3 using the SciPy and scikit-posthocs libraries. For all measures — eye-tracking metrics and questionnaire items alike — normality of distributions was assessed using the Shapiro-Wilk test. Given that at least two variables per measure deviated significantly from normality, the non-parametric Friedman test was applied as the primary inferential test for all analyses, followed by Dunn's post-hoc test with Bonferroni correction for multiple comparisons. The significance threshold was set at $\alpha = 0.05$. Spearman rank correlations were additionally computed to examine the associations between subjective evaluations and objective eye-tracking measures at the level of visualisation grand means (n = 12).

5. Results

5.1 Analysis of the results of the survey responses of the experiment participants

The results of the experiment, conducted with the participation of 65 individuals, reveal a number of interesting issues concerning the perception of space and the experience of it, examined through the use of three questions asked after each visualisation. Statistical analysis confirmed that participants differentiated significantly between the presented interiors across all three evaluative dimensions: perceived calming quality (Friedman test: $\chi^2(11) = 222.65$, p < 0.001), suitability for contemplative practice ($\chi^2(11) = 93.87$, $p < 0.001$), and perceived safety and comfort ($\chi^2(11) = 263.33$, $p < 0.001$). The strongest differentiation was observed for the safety dimension, for which 30 out of 66 pairwise comparisons reached statistical significance after Bonferroni correction, indicating that the sense of safety and comfort was the most discriminating factor in the emotional evaluation of the presented spaces (Figures 15, 16, 17).

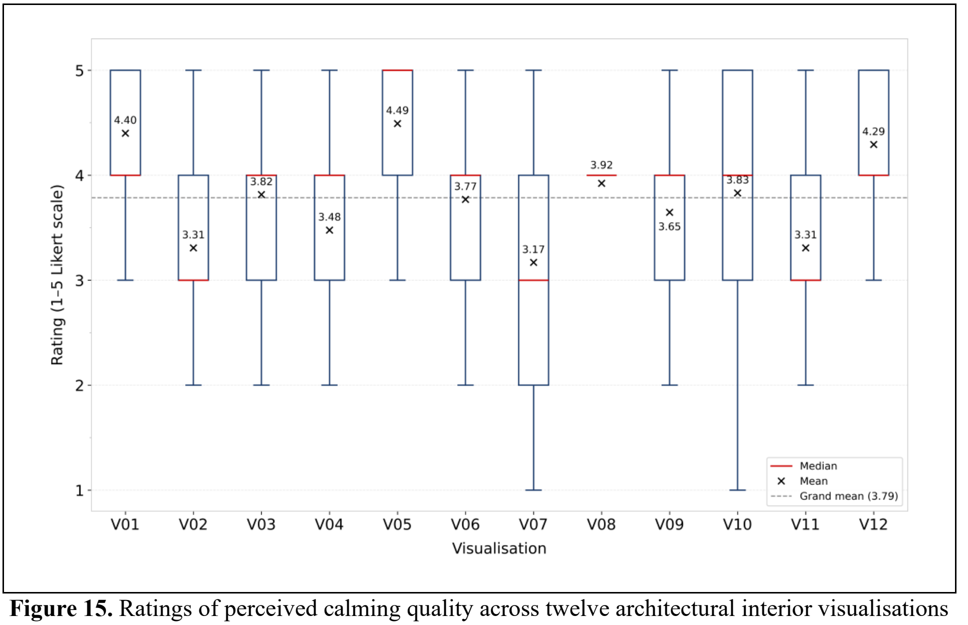

Figure 15. Ratings of perceived calming quality across twelve architectural interior visualisations (V01–V12). Participants responded to the question Q1: “Can the presented space be described as calm and soothing?” on a five-point Likert scale.

The first issue that becomes clearly visible in the results is the convergence of high scores for visualisations V01, V05, and V12. These interiors received the highest mean ratings across all three questions – in particular, V05 achieved the highest ratings for calming quality ($M = 4.49$) and safety ($M = 4.31$) (Figures 15, 17), while V01 and V12 also scored consistently above the grand mean on all dimensions. Post-hoc analysis confirmed that these three visualisations differed significantly from several lower-rated ones, particularly V07 and V11. These spaces were most strongly associated with a sense of safety, as well as with feelings of calmness and tranquillity [40]. Attempting to explain why only these three out of twelve visualisations received such exceptionally high scores is a rather complex task. In order to properly characterise this phenomenon, it is necessary to identify the distinctive and shared features of these visualisations.

The first element that distinguishes these interiors from the remaining twelve is the presence of seating areas designed in the form of low seats, such as poufs and cushions [41]. For the majority of study participants, this way of occupying the space, as well as this type of seating, was associated with a high sense of comfort and safety. Another shared feature is the large amount of light – these are interiors with very good access to sunlight. Two further common characteristics may also be identified: soft curtains by the windows, and flowers and greenery placed in pots inside the rooms. It appears that these four elements alone – or perhaps as many as these four elements – may cause an interior to acquire a cosy and comfortable character for its users [42]. Other features of the visualisations, such as warm colour schemes, are present in all twelve images and therefore cannot be indicated as individual elements responsible for the distinctive quality of these particular visualisations.

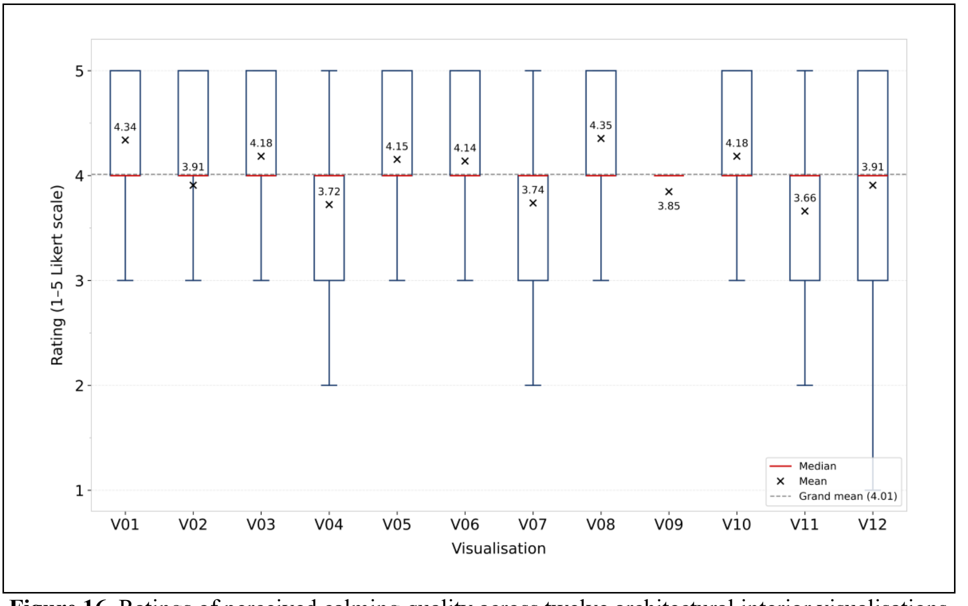

Figure 16. Ratings of perceived calming quality across twelve architectural interior visualisations (V01–V12). Participants responded to the question Q2: "Is the presented space suitable for meditation, concentration, or prayer?" on a five-point Likert scale.

Visualisations V07 and V11 are characterised by the lowest ratings across the set. V07 recorded the lowest mean scores for calming quality (M = 3.17) and safety (M = 2.89) of the entire dataset (Figures 15, 17), with the widest interquartile range on both dimensions, reflecting not only the most negative evaluations but also the greatest disagreement among participants. V11 similarly fell below the grand mean on all three questions (Q1: M = 3.31, Q2: M = 3.66, Q3: M = 3.02) and differed significantly from multiple higher-rated visualisations after post-hoc correction. Several factors may have contributed to this result [43]. These two interiors contain the least amount of light and have small window openings positioned above the human line of sight, contributing to a sense of enclosure and preventing users from looking out at the surrounding environment. Such conditions may evoke the impression of a room with no exit, as if a person were trapped inside rather than occupying the space voluntarily [44]. These interiors also lack greenery. The visualisations present almost empty, austere, and minimalist temple interiors containing an altar and benches. Among the 65 participants, this type of interior was evaluated the least favourably and perceived as the least welcoming – a finding consistently confirmed across all three evaluative dimensions and corroborated by the statistical analysis.

Notably, while V07 and V11 received the lowest ratings for calming quality and safety, their scores for suitability for contemplative practice (Q2) were less extreme – V07: M = 3.74, V11: M = 3.66 – and did not differ significantly from the grand mean of 4.01 (Figure 16) to the same degree as on the other two dimensions. This dissociation suggests that participants distinguished between the emotional discomfort evoked by a space and its perceived functional appropriateness for prayer or meditation, implying that an austere or enclosed interior may still be regarded as suitable for spiritual practice even when it does not feel calm or safe.

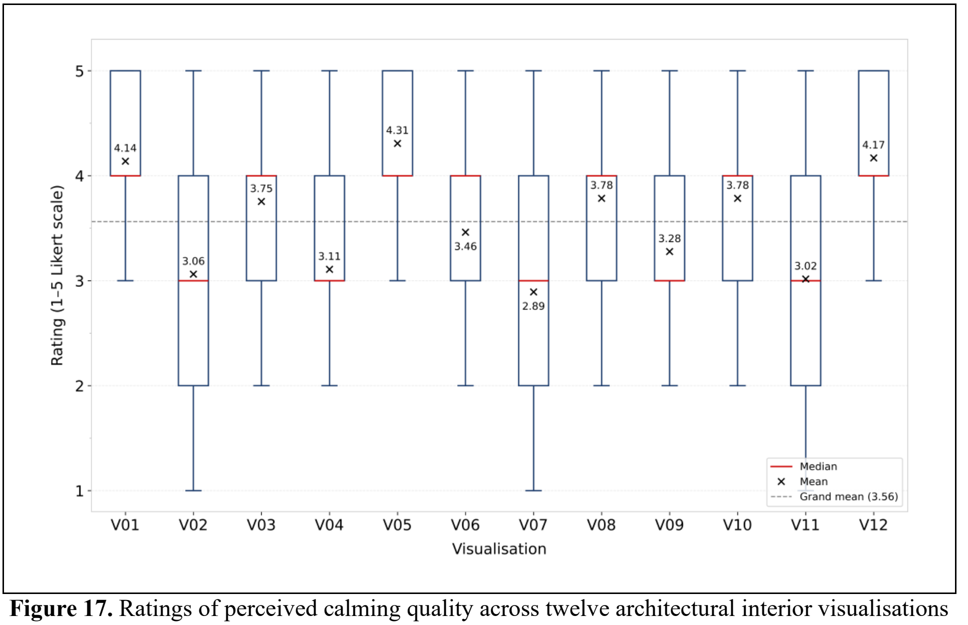

Figure 17. Ratings of perceived calming quality across twelve architectural interior visualisations (V01–V12). Participants responded to the question Q3: "Do you feel safe and comfortable in such a space?" on a five-point Likert scale.

5.2 Analyses of fixation heat map results and selected areas of greatest interest

Below, the results are presented by means of fixation heat maps and areas of greatest interest shown as opacity maps. In the vast majority of cases, two elements of the visualizations accumulate the highest number of fixations: religious symbols, such as the cross or the figure of Jesus, and people, namely the worshippers present inside the temple. Given the character of the space, the perspective, and the framing of the view, it may be stated that the strong interest in the central part of the visualization results from the nature of the place being depicted [45]. Nevertheless, a particularly interesting finding is the extent to which attention is attracted by green plants placed in pots. It may therefore be preliminarily concluded that greenery is a highly desirable element of the interior and has a positive influence on the comfort of occupying a given space. In the background, visual attention is also concentrated on lighting elements, such as wall sconces and small lanterns placed on the walls. A tendency to visually inspect full, uniform wall surfaces is also noticeable. This is probably the result of an attempt to confirm whether these planes indeed contain no elements worthy of attention.

Figure 18. Image number 1, A – results of heat map analysis, I – area of greatest interest at opacity analysis, authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 19. Image number 2, B – results of heat map analysis, II – area of greatest interest at opacity analysis, authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 20. Image number 3, C – results of heat map analysis, III – area of greatest interest at opacity analysis, authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 21. Image number 4, D – results of heat map analysis,
IV – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 22. Image number 5, E – results of heat map analysis,
V – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 23. Image number 6, F – results of heat map analysis,
VI – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 24. Image number 7, G – results of heat map analysis,
VII – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 25. Image number 8, H – results of heat map analysis,
VIII – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 26. Image number 9, I – results of heat map analysis,
IX – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

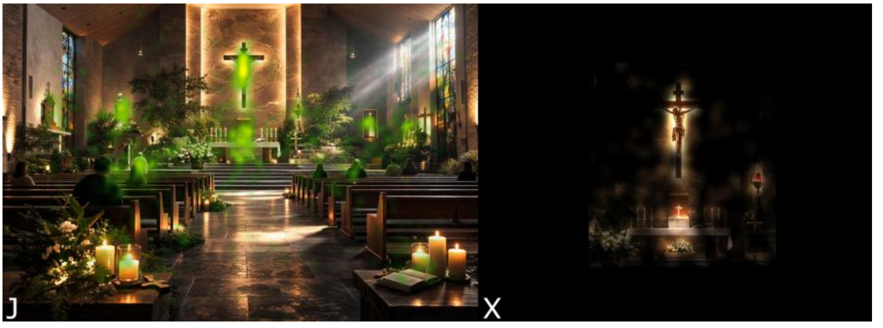

Figure 27. Image number 10, J – results of heat map analysis,
X – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

Figure 28. Image number 11, K – results of heat map analysis,
XI – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

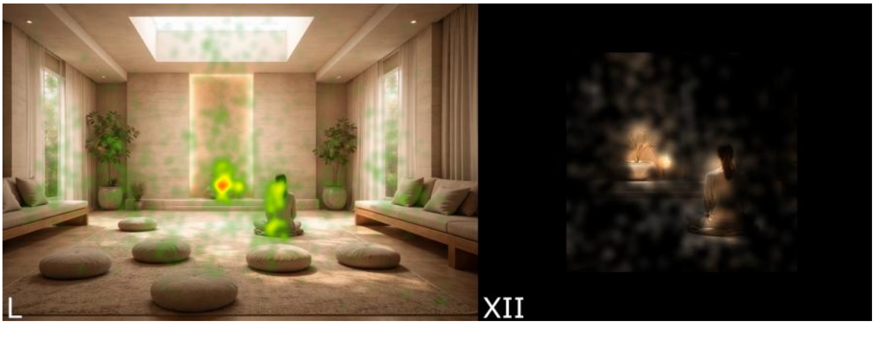

Figure 29. Image number 12, L – results of heat map analysis,
XII – area of greatest interest at opacity analysis,
authors: Wojciech Kocki and Mariusz Dzieńkowski

5.3 Quantitative analysis of eye-tracking and pupillometric data

5.3.1 Fixation duration

Fixation duration (FD) reflects the mean length of time a participant's gaze dwells on a given area of interest across all recorded fixations. Longer fixation durations are generally associated with deeper cognitive processing or sustained affective engagement, while shorter durations indicate rapid perceptual categorisation with limited analytic or emotional investment. In the context of architectural interior visualisations, FD can therefore serve as an indirect indicator of the degree to which a given space captures and holds the viewer's attention beyond the initial orienting response.

Distributions of fixation duration are similar across all visualisations (Figure 30) – medians range from 210 to 260 ms, and IQR values vary from 60 ms (V09) to 90 ms (V03). V09 shows the narrowest interquartile range, indicating the greatest consistency of responses among participants – participants consistently looked at it briefly.

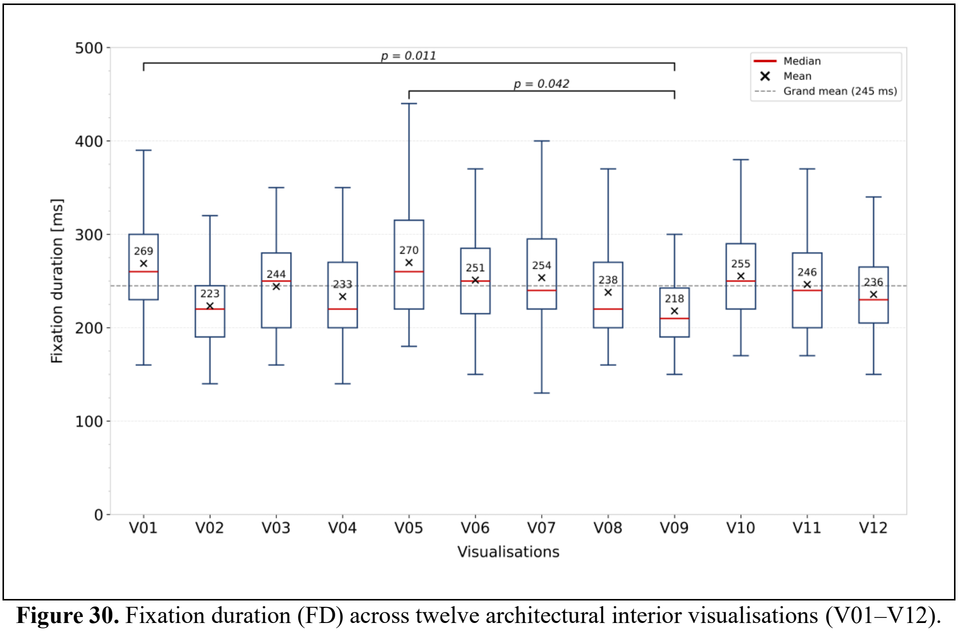

Figure 30. Fixation duration (FD) across twelve architectural interior visualisations (V01–V12). Boxes represent the interquartile range (IQR; 25th–75th percentile), the red horizontal line indicates the median, and the cross (×) denotes the mean value. Whiskers extend to the most extreme data points within 1.5 × IQR; outliers are not displayed. The dashed line indicates the grand mean across all visualisations (244.8 ms). Statistically significant differences between pairs of visualisations are indicated by brackets: * $p < 0.05$ (Dunn's test, Bonferroni correction). Only participants with ≥ 80% valid eye-tracking samples were included (n = 52–56 per visualisation).

All 12 variables deviated significantly from normality (Shapiro-Wilk test, $p < 0.01$ for all), justifying the use of the non-parametric Friedman test. The test revealed significant differences in fixation duration across visualisations: $\chi^2(11) = 39.11$, $p < 0.001$. The grand mean (244.8 ms) runs through the centre of the distributions for most visualisations, confirming the overall homogeneity of the FD measure across this stimulus set. Above the grand mean are V01 (median = 260 ms) and V05 (median = 260 ms); below are V09 (median = 210 ms) and V02 (median = 230 ms). The difference between the extreme medians amounts to only 50 ms, indicating that none of the visualisations engaged visual attention in a manner radically different from the others.

Despite global significance, Dunn's post-hoc test with Bonferroni correction identified only two significant pairs: V01 vs V09 ($p = 0.011$) and V05 vs V09 ($p = 0.042$). Both contrasts involve V09, which recorded the shortest mean fixation duration ($M = 225$ ms, $SD = 55$ ms) and the narrowest interquartile range of all visualisations. This confirms that V09 is the only visualisation distinguished by shortened and consistent fixation duration – a pattern typical of a stimulus processed visually in a rapid and unambiguous manner, suggesting it may function as a spatial reference point rather than a site of deep cognitive or affective engagement. V01 ($M = 281$ ms) and V05 ($M = 293$ ms), by contrast, held gaze the longest, indicating greater processing effort or sustained affective involvement with these interior spaces.

5.3.2 Fixation count

Fixation count (FC) reflects the total number of fixations directed at a given area of interest, serving as an indicator of the depth and intensity of visual engagement. In the context of emotional responses to architectural interiors, a high fixation count suggests sustained affective activation – the visualisation repeatedly attracted the viewer's attention, which may indicate strong aesthetic appeal, emotional ambiguity, or an unresolved affective response to the spatial composition. A low fixation count, by contrast, points to limited emotional engagement, rapid satiation, or indifference toward the presented interior.

Distributions of fixation count reveal a clear bipartite structure across the twelve visualisations (Figure 31), with medians ranging from 7 (V02) to 16 (V12). Two groups are apparent: a high-FC cluster comprising V12 ($M = 15.2$), V09 ($M = 14.4$), V01 ($M = 14.5$), V03 ($M = 14.4$) and V10 ($M = 13.8$), and a low-FC cluster comprising V02 ($M = 7.1$), V08 ($M = 9.6$), V11 ($M = 10.1$), V07 ($M = 10.6$) and V05 ($M = 10.5$).

The Friedman test yielded the strongest result across all three oculomotor measures: $\chi^2(11) = 172.59$, $p < 0.001$. Dunn's post-hoc test with Bonferroni correction identified 28 significant pairs out of 66 possible – nearly half of all pairwise comparisons – confirming that the bipartite structure observed descriptively is statistically robust. The grand mean of 12.1 fixations effectively separates the two groups, with all high-FC visualisations falling above and all low-FC visualisations below this threshold.

Four representative significant pairs illustrate the key contrasts. V02 vs V12 ($p < 0.001$) represents the most extreme contrast in the dataset, indicating that these two visualisations elicited fundamentally different levels of emotional engagement. V08 vs V09 ($p < 0.001$) and V05 vs V09 ($p < 0.001$) confirm that V09 consistently generated stronger affective activation than low-FC visualisations, despite its short individual fixation duration. V11 vs V12 ($p < 0.001$) marks the boundary between emotionally activating and emotionally neutral visualisations within the closest value range.

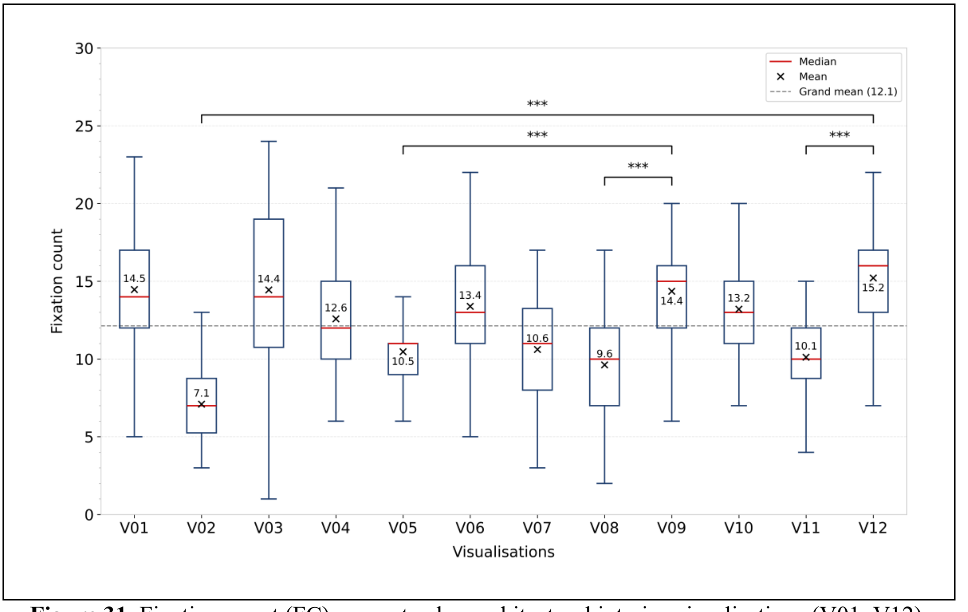

Figure 31. Fixation count (FC) across twelve architectural interior visualisations (V01–V12). Boxes represent the interquartile range (IQR; 25th–75th percentile), the red horizontal line indicates the median, and the cross (×) denotes the mean value. Whiskers extend to the most extreme data points within 1.5 × IQR; outliers are not displayed. The dashed line indicates the grand mean across all visualisations (12.1 fixations). Statistically significant differences between selected pairs of visualisations are indicated by brackets: *** $p < 0.001$ (Dunn's test, Bonferroni correction). Only participants with ≥ 80% valid eye-tracking samples were included ($n = 47$–56 per visualisation).

V02 stands out as the visualisation generating the weakest emotional engagement across all pairwise comparisons, participating in seven significant differences and consistently occupying the low-FC extreme (median = 7, $M = 7.1$). This pattern – the fewest fixations combined with near-neutral pupillary response – suggests emotional indifference or rapid affective satiation: the interior failed to sustain the viewer's emotional interest. The high-FC group, led by V12 and V09, represents visualisations that consistently provoked stronger and more sustained affective responses, indicating greater emotional salience of their spatial and aesthetic qualities.

5.3.3 Pupil diameter

Pupil diameter is the only eye-tracking measure with a direct physiological link to emotional processing. Controlled by the autonomic nervous system independently of conscious volition, pupil dilation reflects sympathetic activation associated with emotional arousal, while constriction relative to the baseline level indicates a return to or stabilisation below the initial orienting response. Crucially, pupil diameter captures the intensity of autonomic arousal without differentiating its valence – the same pupillary response may accompany positive engagement, aesthetic fascination, spatial discomfort, or unresolved affective tension.

In the present study, pupil diameter was averaged across both eyes and normalised to the first second of each stimulus exposure (Sec 1, t = 1 s), which served as the within-stimulus baseline (Figure 32). This approach eliminates luminance confounds arising from differences in brightness between visualisations. The magnitude of the autonomic response was expressed as the absolute percentage change from baseline: |% change| = |Sec N − Sec 1| / Sec 1 × 100, where higher values indicate stronger departure from the initial arousal level regardless of direction. Only participants with ≥ 80% valid samples were included (n = 52–56 per visualisation).

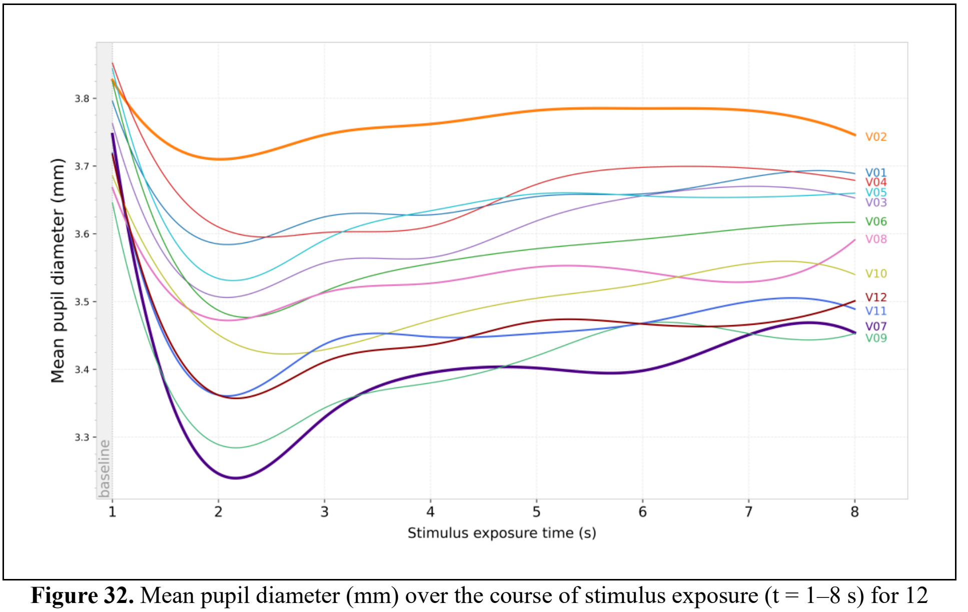

Figure 32. Mean pupil diameter (mm) over the course of stimulus exposure (t = 1–8 s) for 12 architectural interior visualisations (V01–V12). Each curve represents the grand mean across valid participants (≥ 80% valid samples; n = 52–56 per visualisation). The shaded area at t = 1 s indicates the within-stimulus baseline (Sec 1), to which all subsequent values are implicitly referenced. Lines are smoothed using cubic spline interpolation. Line thickness reflects the hierarchy of autonomic arousal magnitude: V07 (strongest response) and V02 (weakest response) are displayed with thicker lines to facilitate visual comparison of the extreme cases.

Three of the twelve variables deviated significantly from normality (Shapiro-Wilk test: V03, V05, V07, $p < 0.05$), justifying the use of the non-parametric Friedman test, consistent with the approach applied to FD and FC. The analysis was conducted on 41 participants with complete data across all twelve visualisations. The Friedman test revealed highly significant differences in autonomic arousal magnitude across visualisations: $\chi^2(11) = 108.13$, $p < 0.001$. Dunn's post-hoc test with Bonferroni correction identified 16 significant pairs out of 66 possible.

The results confirm a clear hierarchy of emotional arousal. V07 generated the strongest autonomic response (M = 9.65%) and differed significantly from seven other visualisations: V01 ($p = 0.0002$), V02 ($p < 0.0001$), V03 ($p = 0.0006$), V04 ($p = 0.007$), V08 ($p < 0.0001$), V10 ($p = 0.0001$), confirming its uniquely activating character across the entire stimulus set. V02 occupied the opposite extreme ($M = 1.57\%$) and differed significantly from six visualisations – V05 ($p = 0.033$), V06 ($p = 0.002$), V07 ($p < 0.0001$), V09 ($p = 0.0001$), V11 ($p < 0.0001$) and V12 ($p < 0.0001$) – confirming the weakest autonomic engagement of all presented interiors.

All twelve visualisations produced pupillary constriction relative to Sec 1, which is physiologically normative: the first second captures the peak orienting response, after which the autonomic system stabilises at a lower arousal level. The magnitude of this stabilisation – and its temporal trajectory over 8 seconds – constitutes the emotionally informative signal.

Four qualitatively distinct trajectory patterns were identified. V02 and V08 showed minimal autonomic response, with flat trajectories remaining close to the baseline throughout the exposure, consistent with emotional neutrality or rapid affective satiation. V03 and V10 exhibited an adaptive recovery pattern – a moderate initial response in seconds 2–3 that gradually attenuated toward baseline by seconds 7–8 – suggesting initial appraisal tension that resolved into affective acceptance as the viewer explored the space. V05, V06, V11 and V12 maintained sustained activation throughout the 8-second window ($|\% \text{ change}| = 5.5\%–7.2\%$) without a clear recovery trend, indicating persistent affective engagement with unresolved valence. V07 produced the strongest and most enduring autonomic response ($|\% \text{ change}| = 9.65\%$), with deep activation at second 2 that remained elevated throughout the entire exposure without recovery – a pattern unique among all twelve visualisations, suggesting prolonged autonomic tension potentially reflecting aesthetic discomfort or spatial disorientation.

The overall arousal ranking – V07 > V12 ≈ V11 > V06 ≈ V09 > V05 > V04 > V10 > V03 > V01 > V08 > V02 – is consistent with the patterns observed in the FC analysis: visualisations generating stronger autonomic activation (V07, V12, V11, V09) largely correspond to those eliciting higher fixation counts, suggesting a convergent affective response across both behavioural and physiological measures. The notable exception is V07, which despite showing the strongest pupillary response did not rank among the highest FC visualisations, pointing to a qualitatively distinct form of emotional engagement – not exploratory, but tension-driven.

5.3.4 Subjective evaluations and eye-tracking metrics: correlation analysis

To examine the relationship between participants' subjective emotional evaluations of the presented interiors and the objective eye-tracking and pupillometric measures, Spearman rank correlations were computed at the level of visualisation grand means ($n = 12$). This approach treats each visualisation as a single data point, characterised by its mean value on each measure across all valid participants, and tests whether visualisations that scored higher on subjective ratings also exhibited systematically different behavioural or physiological responses. Spearman's rank correlation was selected due to the ordinal nature of the Likert scale data and the small number of data points.

The correlation matrix encompassed three subjective measures: Q1 (calm and soothing), Q2 (suitable for meditation or prayer), and Q3 (safe and comfortable), and three objective measures: fixation duration (FD), fixation count (FC), and pupil diameter response magnitude (|% change from baseline|). A total of nine correlation coefficients were computed (Table 1).

Table 1. Spearman rank correlation coefficients (ρ) between subjective evaluations and eye-tracking metrics at the level of visualisation grand means (n = 12).

	FD	FC	Pupil |%|
Q1: calm & soothing	$\rho = 0.374$, $p = 0.231$	$\rho = 0.441$, $p = 0.149$	$\rho = -0.256$, $p = 0.422$
Q2: meditation/prayer	$\rho = 0.371$, $p = 0.235$	$\rho = 0.140$, $p = 0.664$	$\rho = -0.628$, $p = 0.029$ *
Q3: safe & comfortable	$\rho = 0.317$, $p = 0.316$	$\rho = 0.469$, $p = 0.122$	$\rho = -0.221$, $p = 0.491$

* $p < 0.05$. All other correlations non-significant after Bonferroni correction.

Of the nine correlations tested, only one reached statistical significance: the association between Q2 and pupil diameter response magnitude ($\rho = -0.628$, $p = 0.029$). This negative correlation indicates that visualisations rated as more suitable for meditation, concentration, or prayer generated weaker autonomic arousal responses – that is, smaller departures from the within-stimulus baseline in pupil diameter. Visualisations perceived as most conducive to contemplative practice, such as V05 and V08, were associated with lower physiological activation, while those rated lower on Q2, particularly V07 and V11, produced stronger autonomic responses. This finding is consistent with the neuroscience of focused attention and contemplative states, in which reduced sympathetic activation is a prerequisite for sustained inward concentration.

The remaining correlations were not statistically significant, though several displayed meaningful tendencies. Fixation count showed moderate positive associations with Q1 ($\rho = 0.441$) and Q3 ($\rho = 0.469$), suggesting that visualisations evaluated more positively tended to attract more fixations – consistent with the interpretation that emotionally favourable spaces sustain visual engagement. Fixation duration showed similarly modest positive correlations with all three subjective measures ($\rho = 0.317$–0.374).

The correlation between Q1 and pupil diameter ($\rho = -0.256$) and between Q3 and pupil diameter ($\rho = -0.221$) were both negative in direction, consistent with the hypothesis that higher autonomic arousal accompanies lower perceived calm and safety. Although these coefficients did not reach significance, their direction supports the broader pattern identified in the data and is theoretically coherent with the pupillometric findings reported in the preceding section.

The correlation analysis additionally served the purpose of resolving the valence ambiguity inherent in pupillometric data. Since pupil diameter reflects arousal intensity without differentiating positive from negative emotional states, the direction of its association with subjective ratings is required to interpret its meaning. The consistent negative direction of all pupil-Likert correlations, combined with the finding that visualisations producing the strongest autonomic responses (V07, V11) also received the lowest ratings for calm and safety, confirms that high pupillary activation in this study was predominantly associated with negative affective valence – discomfort, unease, or spatial tension – rather than positive excitement or aesthetic fascination. The notable exception is V12, which combined high autonomic arousal with high subjective ratings, illustrating that positive high-arousal states are possible within this stimulus set but represent a qualitatively distinct affective profile from the negative high-arousal pattern exhibited by V07 and V11.

6. Conclusions

The results obtained appear to be highly promising. The analysed AI-generated visualisations enabled a more detailed examination of how interiors are perceived both emotionally and technically through the use of eye-tracking technology combined with subjective self-report measures. The set of twelve interiors provided a sufficient amount of data on the basis of which several conclusions were formulated.

The study did not identify a single architectural space that was unambiguously best or worst across all measures. Instead, it revealed distinct emotional profiles in which different dimensions of reception – attentional, exploratory, autonomic, and subjective – provide a complementary rather than identical picture of how each interior is experienced.

With regard to the perception of interiors and the experience of their calming, soothing, and atmospheric qualities, four factors were found to have a particularly strong influence:

- very good natural lighting;
- interior furnishings related to seating areas, including soft elements such as poufs and cushions;
- soft, textile-based finishes on walls and windows, including curtains;
- green and plant-based elements within the interior, such as potted plants.

These elements contribute to the cosiness of a space and to the user's sense of safety – factors closely associated with the finishing characteristics of residential rather than monumental spaces. This interpretation is supported by the quantitative data: visualisations V01, V05, and V12, which incorporate these elements, received the highest mean ratings across all three evaluative dimensions and differed significantly from the lowest-rated visualisations in post-hoc analyses.

Visualisation no. 05 achieved the highest subjective ratings across all three questions with a moderate autonomic arousal response, while fixation count and fixation duration did not distinguish it from the group average. This profile – high subjective quality combined with moderate, positive physiological activation – represents the most desirable outcome in the context of sacred and meditative architecture: a space perceived as calm, safe, and appropriate for contemplation without generating excessive emotional tension.

Visualisation no. 12 presents a qualitatively different but equally positive profile: the highest fixation count, high autonomic arousal, and high subjective ratings. It is the only visualization in which strong physiological activation co-occurs with a positive subjective evaluation – a pattern characteristic of positive aesthetic engagement, in which the space attracts gaze, activates the viewer emotionally, and is simultaneously well received. V12 thus represents the most engaging interior in the evaluated set.

In terms of visual attractors that draw attention and increase the number of fixations, the following elements were identified:

- human figures;
- religious symbols located in the central part of the interior, including sculptural representations of the human figure;
- plant elements.

In contrast, visualisations no. 07 and 11 received the lowest ratings across the set. V07 produced the strongest and most persistent autonomic arousal response, the lowest fixation count, and the lowest subjective ratings for calming quality and safety. The convergence of strong physiological activation with negative subjective evaluation resolves the valence of this response as negative – the arousal evoked by V07 reflects discomfort or unease rather than aesthetic fascination. These two interiors contain the least natural light, have small window openings positioned above the human line of sight, and lack greenery, contributing to a sense of enclosure that may evoke the impression of involuntary confinement. Of all the evaluated interiors, V07 requires the most substantial design revision.

Visualisation no. 02, by contrast, exhibited a pattern of consistent emotional indifference: the lowest fixation count, the weakest autonomic response, and below-average subjective ratings. No measure – behavioural, physiological, or evaluative – indicated meaningful engagement. In the context of designing spaces for contemplation, this outcome is particularly undesirable: a sacred interior should engage its users rather than leave them indifferent.

A key methodological finding of the study is the distinction between two qualitatively different types of high autonomic arousal:

Negative arousal, observed in V07 and V11, is characterised by strong physiological activation accompanied by low subjective ratings, low perceived safety, and limited exploratory behaviour – a pattern consistent with aesthetic discomfort or spatial disorientation.

Positive arousal, observed in V12, involves equally strong physiological activation but accompanied by high subjective ratings and high fixation count – aesthetic excitement rather than threat response. This distinction would have been impossible without the simultaneous application of pupillometry and subjective self-report measures, underscoring the methodological value of their integration.

The only statistically significant correlation between subjective and physiological measures (Q2 × pupil: $\rho = -0.628$, $p = 0.029$) indicates that spaces rated as more suitable for meditation and prayer generated weaker autonomic responses. This finding is consistent with the neuroscience of contemplation – focused attention and inner calm require reduced sympathetic activation [46]. The direct design implication is that sacred or meditative interiors should be designed to minimise stimuli that generate autonomic tension and maximise elements conducive to calm, with V05 and V08 serving as positive models.

In seeking an answer to the research thesis – "Which interior elements in sacred spaces contribute to a high level of concentration for meditation, a sense of comfort, and emotional calm?" – several variables must be considered. A general characteristic relevant to this type of interior is its intimate spatial quality: the interior should be designed as closely as possible to the human scale, as the stronger the effect of monumentality, the lower the perceived level of cosiness. Positive outcomes are associated with soft and textile elements of interior finishing and furnishing. Upholstered seating, poufs, and cushions positively influence the user's sense of safety, while the introduction of plant elements – whether in the form of potted plants or visible greenery through large windows – has a consistently positive impact on the perception of the space. Finally, providing visual contact between the person inside the interior and the external environment through windows or wall openings contributes substantially to perceived safety, as confirmed by both the subjective ratings and the physiological data.

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