INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 15, Issue 3, 2024: 1327-1350 www.ijcs.ro

DOI: 10.36868/IJCS.2024.03.12

ARCHITECTURAL VISUAL DESIGN – EYE-TRACKING ANALYSIS OF CHURCH ALTARS: A CASE STUDY

Wojciech KOCKI[1,*], Mariusz DZIEŃKOWSKI[2]

[1] Lublin University of Technology – Faculty of Civil Engineering and Architecture, Department of Contemporary Architecture, 38D Nadbystrzycka Street, Lublin - Poland, 20-618
[2] Lublin University of Technology – Faculty of Electrical Engineering and Computer Science, Department of Computer Science, 38A Nadbystrzycka Street, Lublin – Poland, 20-618

Abstract

Different types of altars provide examples of architectural solutions regarding correct and effective design. The differences lie in the use of different stylistic treatments, colors and chiaroscuro. The interior of the church and the central feature in the form of an altar create an environment in which the faithful devote themselves to prayer. Both stylistic and color solutions can influence the level of prayer contemplation and concentration during mass and other services. The research included selected altars from churches in Lublin, Poland. Attention was paid to which elements in the photos attract the eye and determine observation and focus. This paper dicusses a series of studies on the best-designed architectural spaces that increase concentration during meditation and prayer. Moreover, it analyzes the existing interiors of churches along with altars and formulates conclusions regarding design guidelines for newly constructed buildings.

***Keywords**: Architecture, Visual design, Eye tracking, Altar, Visual analysis*

Introduction

The architecture of religious buildings undergoes periodic modifications and alterations as part of church upgrade projects and in response to the individual needs of parishes. Religious buildings erected several centuries ago have, in most cases, retained their original form, with the exception of minor interior changes. Usually, after a church is built, its external architecture and interior design do not undergo significant alterations. However, there are substantial differences in how the character of the interiors in individual buildings is perceived. The design of the church's interior may influence concentration and meditation levels during mass. Thanks to the possibilities offered by eye-tracking technology, we are now able to determine whether or not the church interior uses multiple visual stimuli and if so, to what degree. The experiment presented in this paper aims to analyze the existing church interiors along with altars and formulate conclusions regarding design guidelines for newly constructed buildings or for upgrade projects involving existing structures.

The obtained results and observations can apply to both religious interiors and secular buildings. The described experiment and its outcomes are the first part of preliminary, multidisciplinary research paving the future path of research projects in this area. The first preliminary-research stage involves an experiment. In the next stages, the experiment will be developed into more complex forms. For example, it may be expanded by introducing EEG measurements during eye-tracking testing [1]. Eye-tracking technology is not only an

* Corresponding author: w.kocki@pollub.pl

interdisciplinary but also a flexible method, enabling extensive analysis through the processing of the obtained data [2].

The main thesis of this research is that "a multitude of interior design elements and extensive altars influence concentration and meditation levels, which translates into dynamic eye movement in church attenders". For the purposes of the study, an experiment was performed using eye-tracking technology.

Some scientific reports in the field of eye-tracking research demonstrate the importance of the face and its elements as most powerful visual attractors [3]. The examined samples of altar photos contain fragments of people's faces. Due to the large number of other architectural and interior design elements appearing in the photos, the authors decided not to remove faces to corroborate these results.

The purpose of the research is significant for many scientific disciplines such as architecture, computer science, sociology and interior design. Understanding the properties of space perception through human vision is a very important design element. A better understanding of design possibilities will considerably increase the level and quality of creating interiors of churches and other facilities. The scope of the research enables continuation and dissemination of research results in different forms in many scientific disciplines.

The internal space of religious buildings with a centrally located altar should promote silence and concentration to allow the maximum level of meditation. This is related to the function and purpose of such spaces. The preferred interior for a praying environment is one that promotes peace. Today's religious knowledge and information flow is very much different than in medieval times. Nowadays, the *biblia pauperum* no longer exists in its original form. The faithful who come to church usually read and write and most are educated. The time spent in the temple during church rituals, masses and holidays is a time of conscious participation. Nowadays, followers of every religion stay in temples of their own will and need. It is worth undertaking analytical work to design spaces where meditation and prayer can be achieved at the highest level. Elements that distract and disrupt these activities may be placed in other spaces of the temples and not in the main nave. This applies to newly constructed projects that can be designed this way from the beginning. Interfering with existing historical structures would be impossible and unjustified [4]. The experiment, research and conclusions are mainly intended for structures that will be designed in the future. The authors do not question the current interior design solutions in existing churches. The research solely aims to improve prayer and meditation conditions for the faithful. It respects tradition and commonly accepted religious conventions.

In architectural research, certain regularities resulting from human nature are visible through using the eye-tracking method. An example would be examining the street frontage of a single-family housing estate using this method. In the case of single-family houses, the most noticeable feature of the façade was the porch with a colonnade and the main entrance [5]. It can be suggested that each type of architectural object or interior design will have elements most noticeable to the human eye. This is probably related to human nature, the need to explore the world we are looking at through the mind and to feel safe.

The experiment and study discussed here comprise the second stage of research in the field of spatial perception examined using the eye-tracking method. The authors performed an experiment to examine interiors of various types and furnishings. The results indicate certain regularities in how the human eye is attracted to places of high contrast, located in the center of the examined photos and inscriptions in the form of letters and numbers [6].

The analyzed churches were deliberately selected and come from different time periods from historical to contemporary ones. The date of construction of the churches ranges from the 16th century to the 20th century. The churches were selected from different historical periods so as not to define the impact of their interior architecture on the purpose of the research. Some of the interiors are more elaborate in details and ornaments and others are sparse in form and minimalist. The style of the churches reflects various trends. These are Renaissance, eclectic, modernist and minimalist elements.

Experimental part

Materials

The materials used in the experiment are visual stimuli in the form of photos of 12 altars in Catholic churches (Fig. 1). The altars were selected to represent different periods to allow the comparison of the interior styles of old and new churches. Each frame was taken from churchgoers' most preferred position – the axis of the altar. The frames were kept in an axial, symmetrical, single-point composition. The photos were taken randomly at different times of the day to reflect as closely as possible the actual everyday view of the altar. This means that in some images, there is an empty church, some show a few people inside, while others were taken during a mass.

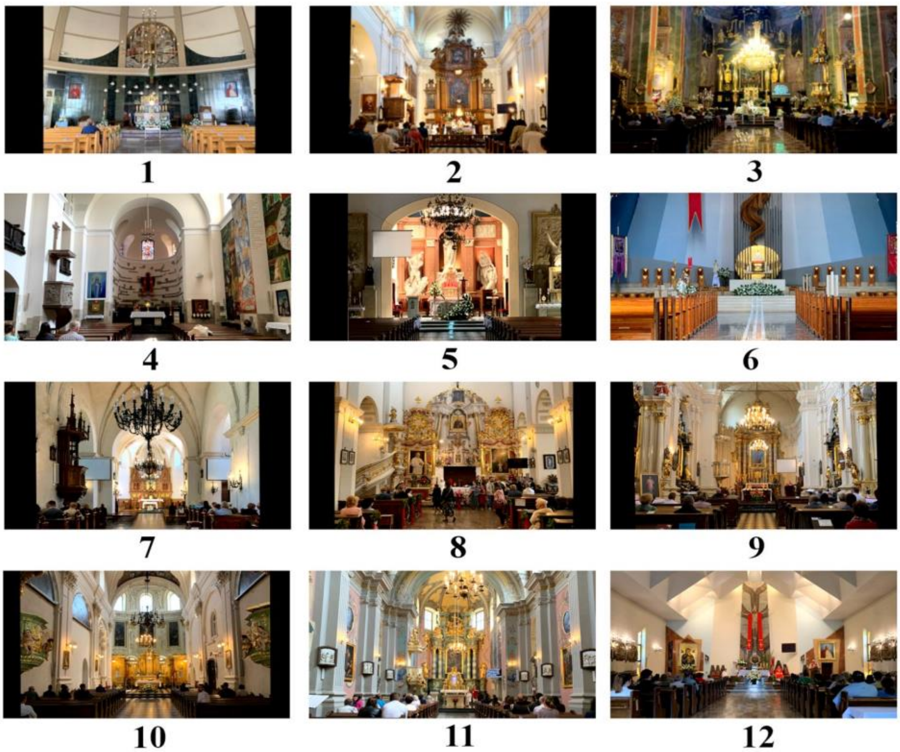

Fig. 1. Images taken for the experiment and used in the eye-tracking study

Additionally, two variants of each view were developed. One show blurred color tones and the other shows the level of contrast and chiaroscuro examined in black and white shades. The blurring of colors makes it possible to verify whether the color (warm or cool) is important when observing the altar. The second variant allows us to validate whether significant contrast and chiaroscuro differences can influence the eye's attraction to specific places where increased fixations were observed.

Figure 1 shows the twelve photos of altars that were included in the experiment. Different styles and ages of the churches were deliberately mixed in the sequence of the photos so as not to accustom the study participants to one interior design style. The photos were prepared in such a way as to ensure that their general characteristics matched each other in terms of color brightness. This procedure was used to avoid differences only due to the level of interior brightness.

The above photo modifications in figure 2 show the color tones present in the analyzed photos. Simplifying colors by using blur reveals more compact spots that can be classified as warm or cool. The classification included only the areas with the highest fixation levels. The distinction between warm and cool color tones provides an additional analytical measure to verify whether the color type is important in regard to the spots that attracted study participants' eyes the most [4].

Due to the interior design of the churches and their architectural styles, their colors are usually warm. However, there are exceptions, such as the interior of church number six, decorated in cool, blue colors. Warm colors in interiors are also associated with artificial lighting. In most cases, the bulbs and light fixtures used are kept below 3500 K. This produces a yellow, warm glow of light in the interior. Despite this phenomenon, there are cool colors in the photos that merit analysis.

In addition to color analysis, color modifications of the examined photos were made in the context of the contrast level of the examined spots with the highest fixation intensity. By additionally verifying whether contrast is important when the eyes choose areas with the highest fixation, it is possible to check whether dark or light spots are important during observation (Fig. 3). The photos were processed by introducing black and white tones and simplified by blurring to eliminate most details. In this way, it is possible to clearly determine whether there is an area of high, medium or low contrast in a given spot with increased fixation [5].

Fig. 2. Colour analysis of images prepared for the experiment and used in the study

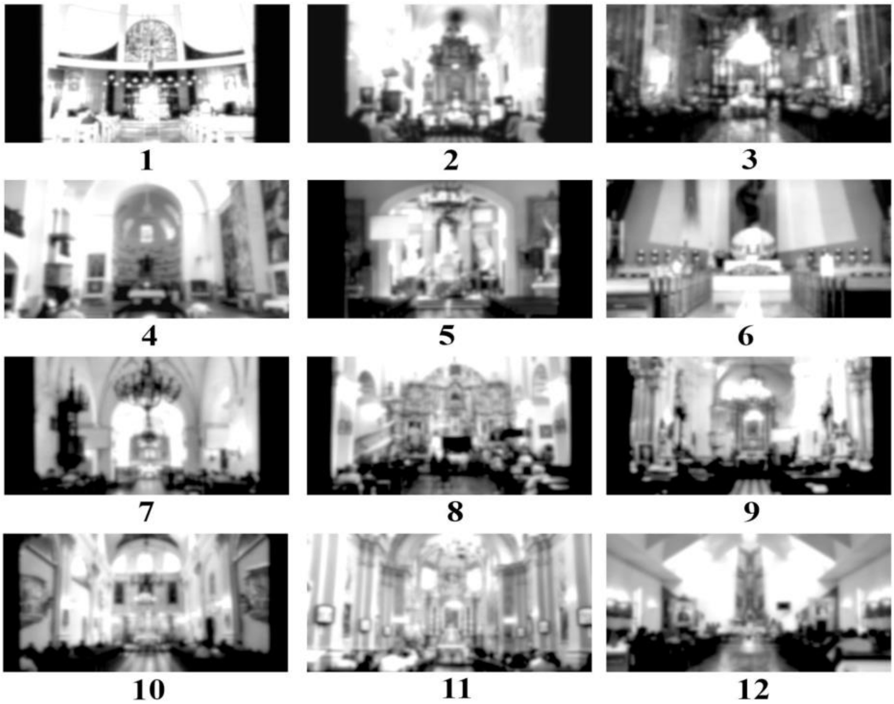

Fig. 3. Contrast analysis of images prepared for the experiment and used in the study

Methods

To obtain eye activity parameters, the study employed the eye-tracking technique. In the study, it was possible to monitor eye movements thanks to a remote, binocular video-based eye tracker – Tobii TX300 – which utilizes near-infrared technology and uses a dark pupil and corneal reflection method to calculate the gaze position. The device collects gaze positions at 300Hz, meaning about 3-ms temporal resolution. The gaze accuracy of this eye tracker is 0.5° in ideal conditions. Moreover, the device allows free head movement in the following range: width – 37cm and height – 17cm, with a 65cm distance from the participant's eyes to the eye tracker [7].

In the study, there were 39 subjects aged between 20 and 30 with normal or corrected-to-normal vision. They were students of two study programs: Architecture and Computer Science at the Lublin University of Technology.

All the stimuli used, i.e., 12 slides with photos of church altars, were displayed on a 23-inch widescreen TFT monitor (1920 x 1080 pixels) integrated with the eye tracker unit. The experiment was performed on the Asus G750JX-T4191H laptop (Intel Core i7-4700HQ, 8GB RAM, Windows 10) using Tobii Studio 3.3.2 software (Tobii AB, Stockholm, Sweden). The distance between the participant's eyes and the screen ranged from 60 to 75cm.

At the start of the experiment, conducted in a quiet testing room with artificial lighting, each participant was asked to sign a consent form and was requested to sit in an upright chair. To minimize movement, participants were instructed to keep their gaze on the screen throughout the experiment. To ensure accurate measurements, a calibration procedure was conducted with a nine-point process. Before beginning the study, each participant was thoroughly informed about the study's purpose and procedure, the operation of the apparatus and the number of boards showing church altars.

During the experiment, on the laptop screen, each subject was presented with 12 slides showing church interiors. Each board was displayed in a fixed order for 5 seconds. The participants could freely examine the slides shown during this time since they had no defined task to perform.

This resulted in 43 video registrations. The videos include sequentially displayed boards with photos of church interiors with an indicator superimposed in the form of a circle representing the current location of the subject's attention.

The data was then processed into fixation maps and heat maps using Tobii Studio software. Heat maps visualize the subjects' attention, showing their distribution and concentration and by using different colors, provide a more intuitive understanding of attention levels. The intensity of a specific activity determines the color. This allows for a quick and easy understanding of the data. Displaying the data directly over the items to which they apply facilitates the reading of heat maps since it reduces mental effort [8]. This visualization method helps detect objects or areas more or less engaging to observers.

Heat maps can show different aspects of eye movement such as the number of fixations and the absolute or relative duration of fixations. The maps based on the number of fixations show the cumulative number of fixations among participants. Each fixation made by each participant adds a value to the color map at the fixation spot [7]. The choice of the appropriate type of heat map depends on the study objectives and the measures of eye movement used to achieve those objectives. The fixation count heat maps selected for the analyses are appropriate when the purpose of the study is to determine the amount of interest generated by the various stimulus elements during a free browsing task, i.e., a task without specific task instructions [9], as was the case in this study.

Figures 6.A-17.A show heat maps generated for successive slides shown to the participants during the experiment. To visually compare the level of attention from different stimuli, it was necessary to globally scale (normalize) the data. After this operation, the amount of heat will be proportional to the level of the represented variable – in this case, the number of fixations. There is no established process for selecting the appropriate upper threshold. Hence, this must be done experimentally so that the heat map correctly reflects the range of values from the perspective of the study being performed [8]. These procedures enable easier visual evaluation of the data.

For the purposes of this study, it was necessary to apply a metric to indicate the intensity of attention (IA) focused on a given area. Hence the use of the term, which means concentration of fixations per unit area. For the 12 stimuli used, the maximum fixation counts ranged from 10 to 20 fixations per unit area (fpa). The default area has a radius of 50 pixels and the mean fixation intensity for all visualizations is close to 15 fpa. This means that fpa was taken as the threshold (red indicator) for all the stimuli (Fig. 4). Subsequently, the level of attention intensity expressed by the number of fpa was analyzed (Table 1) for the elements that elicited the strongest interest in the respondents (the level of IA in the hot areas on the objects observed).

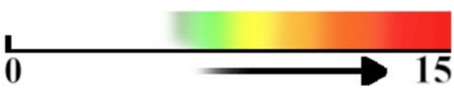

Fig. 4. The legend for all heat maps after normalization, number of fixations

Hot areas of heat maps, i.e., large concentrations of attention on the objects of the presented stimuli, created areas of interest (AOI). The generation of descriptive statistic measures (quantitative data for the defined areas) was used for further qualitative analyses (data-driven creation of AOI). The AOI analysis is a technique to analyze eye movements by assigning them to specific areas or elements of the visual scene [10-12]. Areas of interest, consisting of geometric shapes around relevant areas of visual stimuli, allow researchers to analyze different visual indicators in these areas and compare them [13]. The following were considered for the analyses: time to the first fixation in a given AOI (TTFF), average fixation duration (FD) in AOI, as well as percentage fixated (PF).

The average TTFF allows the determination of the average time to look at the area for the first time, expressed in seconds. It is possible to choose several AOIs and compare which were the most important or attractive for respondents. Another measure used is the average fixation duration (in seconds), which is the time that shows how long the average fixation lasted. In general, fixation durations are around 200–300 ms long and longer fixations indicate deeper perceptual and cognitive processing [10, 11]. By comparing average fixation duration across AOIs, it is possible to distinguish areas that were looked at for a longer time than other areas. The last parameter indicates the percentage of participants that fixated a minimum of once within an AOI (in %).

In addition to the heat maps, figures 6.B-17.B present scan paths for all the subjects. The scan paths show the sequence and positions of fixations (circles) connected by lines (saccades) representing gaze movements on a static media [7]. The size of the circles indicates the fixation duration and the number in the circles represents the order of the fixations. Gaze charts can illustrate the gaze pattern of a single test subject during the entire eye-tracking session, or of several subjects in quick succession [7]. The paths for each participant are differentiated by color. The scan path analysis is valuable for exploratory tasks that do not have a specific target [12].

Figure 5 presents one of the study participants in front of a monitor with an eye-tracking measuring device [14]. An additional research method used in the study involved comparing color and contrast in spots with an increased level of fixation. Appropriate graphic processing of the photos was performed to highlight differences in color and contrast levels [15]. The comparison of these parameters aims to verify whether the warm or cool color and low or high contrast levels are important when choosing a spot with increased fixation.

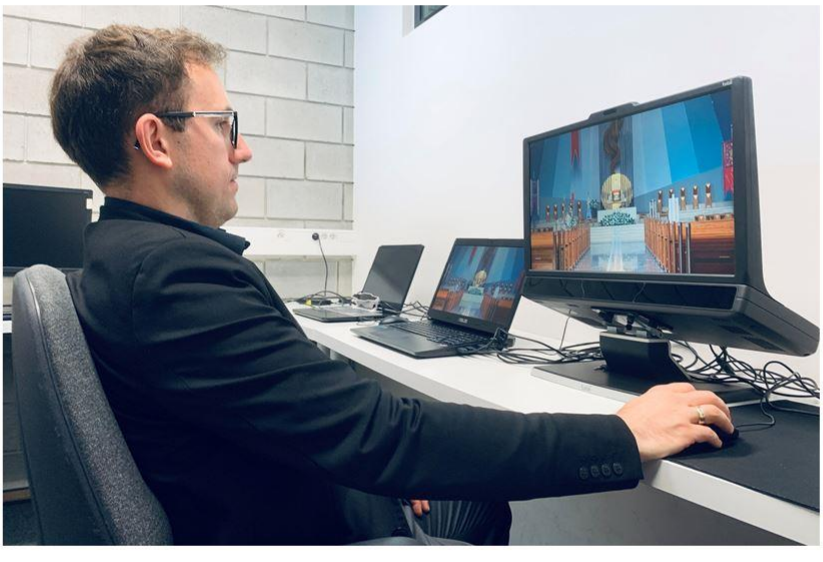

Fig. 5. Photo taken during the experimental study on the remote, binocular video-based eye tracker Tobii TX300

Results and discussion

The main objective of the study is to preliminarily verify what church elements attract the most visual attention. The interiors of religious buildings are very specific spaces where people pray and meditate. To achieve such a spiritual state, special requirements are needed regarding space to increase attention levels. Inspecting eye-catching points and their possible elimination can be used to help the faithful achieve higher concentration levels during mass or prayer time by removing visual stimuli that excessively stimulate eye movement.

Below are the results for 12 photos of altars along with heat maps and fixation points for each. Furthermore, the most characteristic element the 39 participants viewed most frequently in each photo was selected for each image (Figs 6-17). The selection of these spots is crucial to test the thesis and the research results. Each of the selected characteristic spots in the 12 photos was additionally compared in terms of color and contrast levels [5]. The comparison is intended to exclude their significance. The study is intended to confirm that the most important element in the visual perception of an interior is the subject, the element the viewer is looking at. After a preliminary analysis, two types of such elements were selected. These are silhouettes of people and their faces, not only living people but also silhouettes shown in paintings or sculptures [16].

The second group are architectural elements of the interior which were analyzed more often by the experiment participants due to their properties [17]. For the authors of the research, the extremely important elements are those at which people did not look. These elements are valuable for formulating guidelines for the design of new sacred architectural objects. The elements of the interior that people do not look at are not attractive to the eye because they do not attract it in any way. Therefore, using these unattractive elements in newly designed interior projects will increase concentration levels to the maximum because the eye will not receive points in space that focus its attention. Observing the research results in reverse puts the possibilities of eye-tracking technology in a new light. Instead of looking for observation points, it is possible to look for the areas and points that the participants did not look at. These elements can be used to design specific architectural spaces of a calm and soothing nature [18].

Fig. 6. Image number 1, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3, 4 – comparison of image fragments with intense fixation with the color hue and contrast level

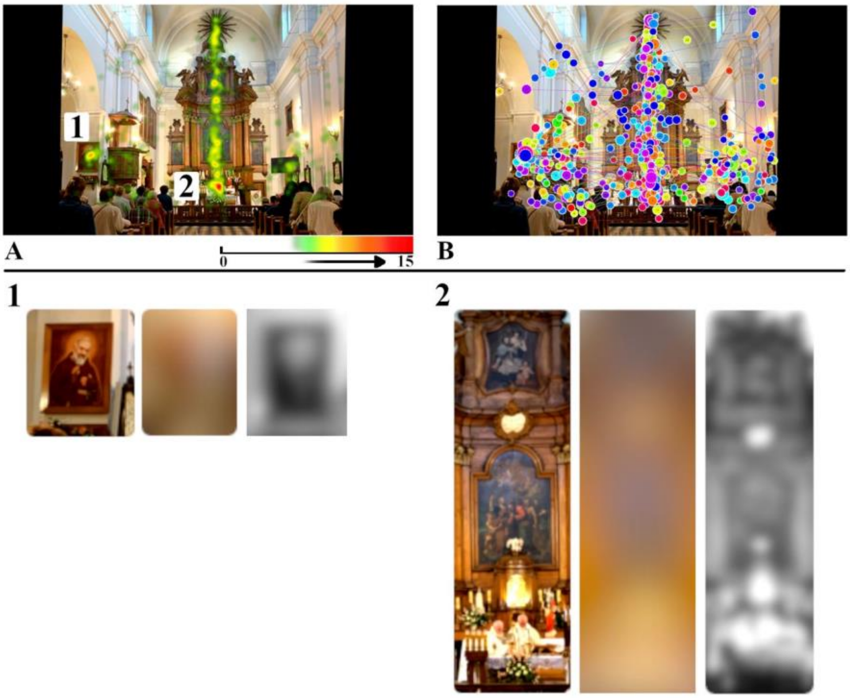

Fig. 7. Image number 2, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2 – comparison of image fragments with intense fixation with the color hue and contrast level

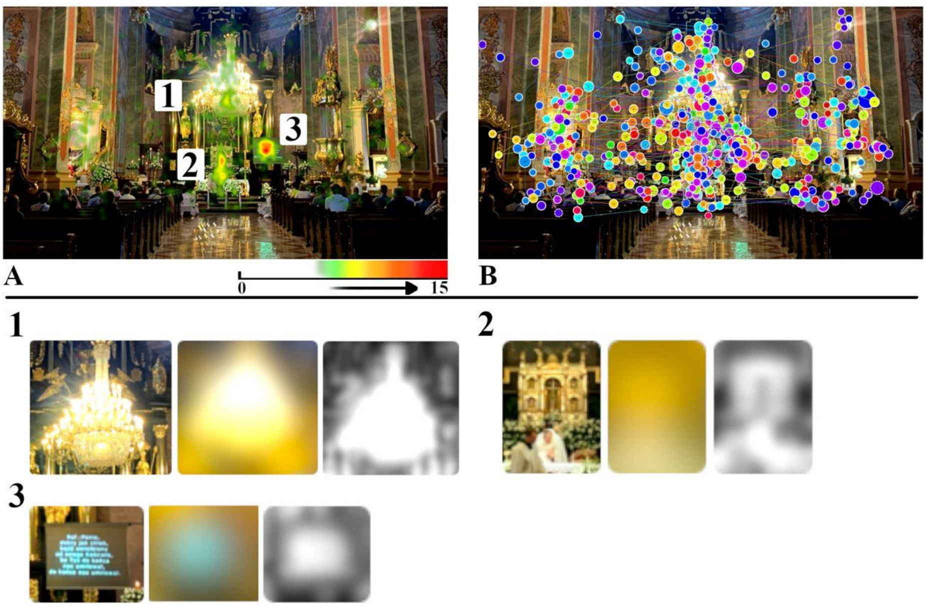

Fig. 8. Image number 3, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3 – comparison of image fragments with intense fixation with the color hue and contrast level

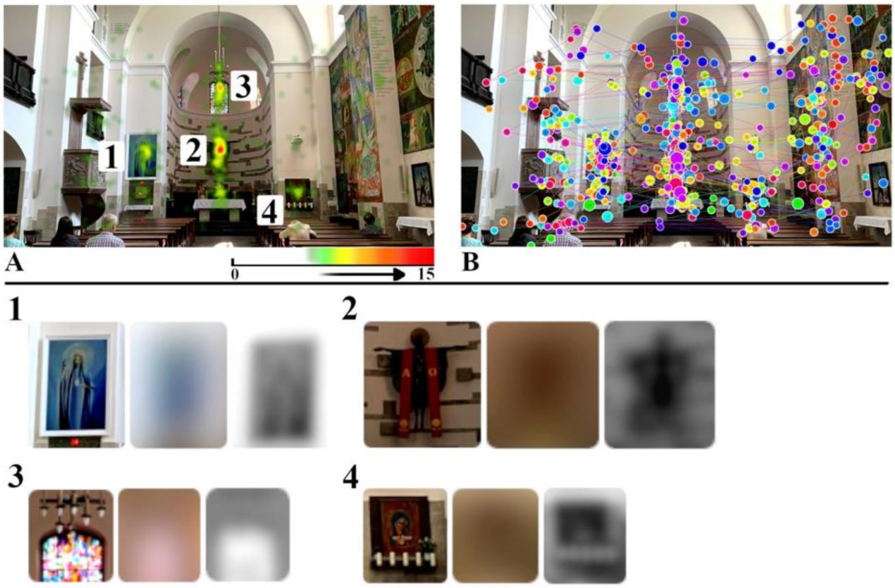

Fig. 9. Image number 4, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3, 4 – comparison of image fragments with intense fixation with the color hue and contrast level

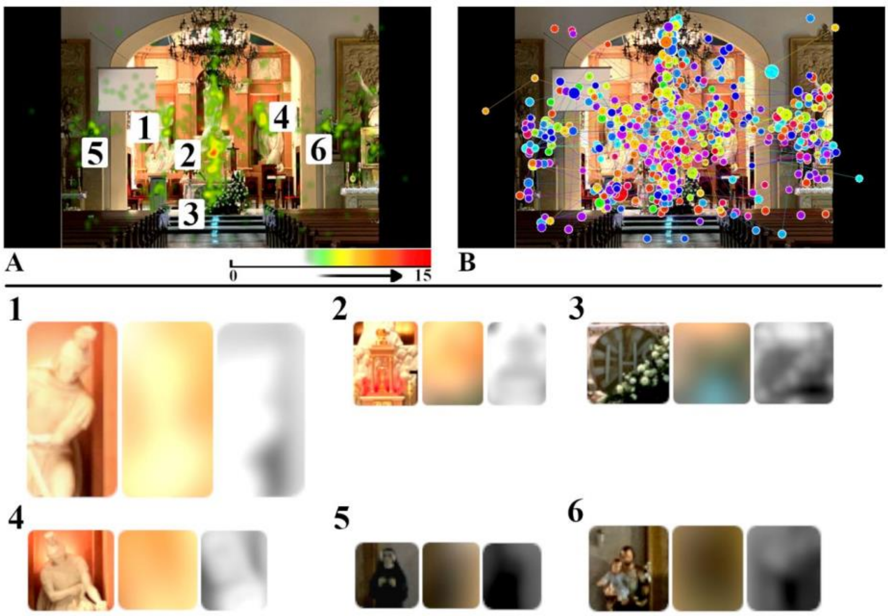

Fig. 10. Image number 5, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3, 4, 5, 6 – comparison of image fragments with intense fixation with the color hue and contrast level

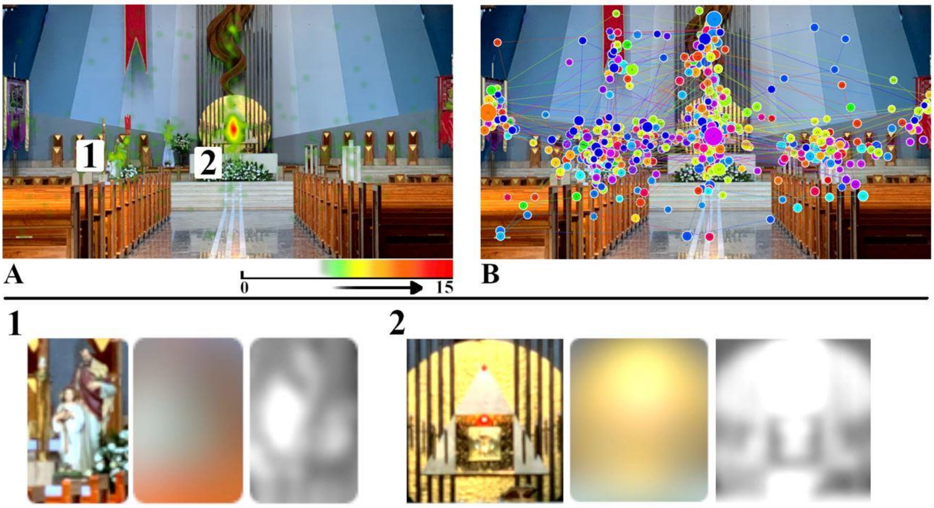

Fig. 11. Image number 6, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2 – comparison of image fragments with intense fixation with the color hue and contrast level

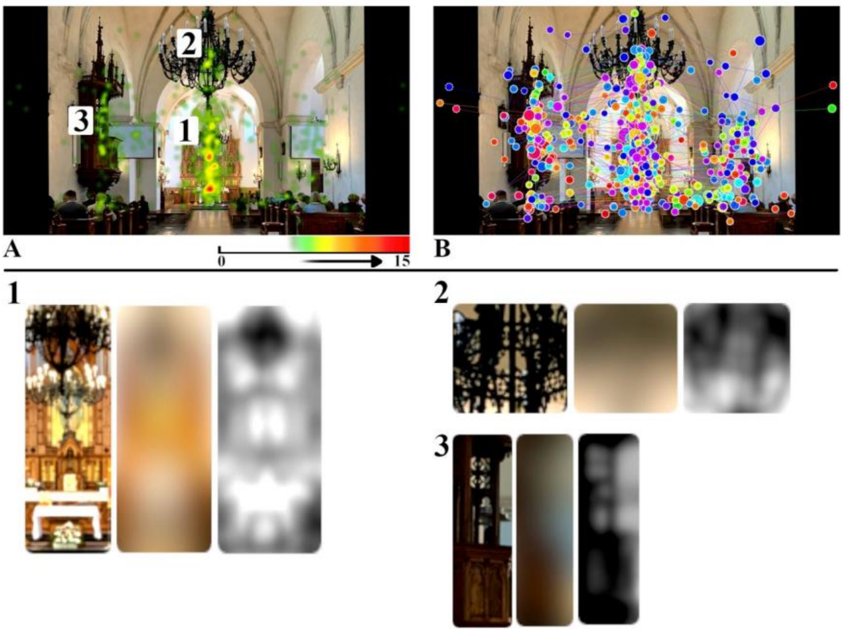

Fig. 12. Image number 7, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3 – comparison of image fragments with intense fixation with the color hue and contrast level

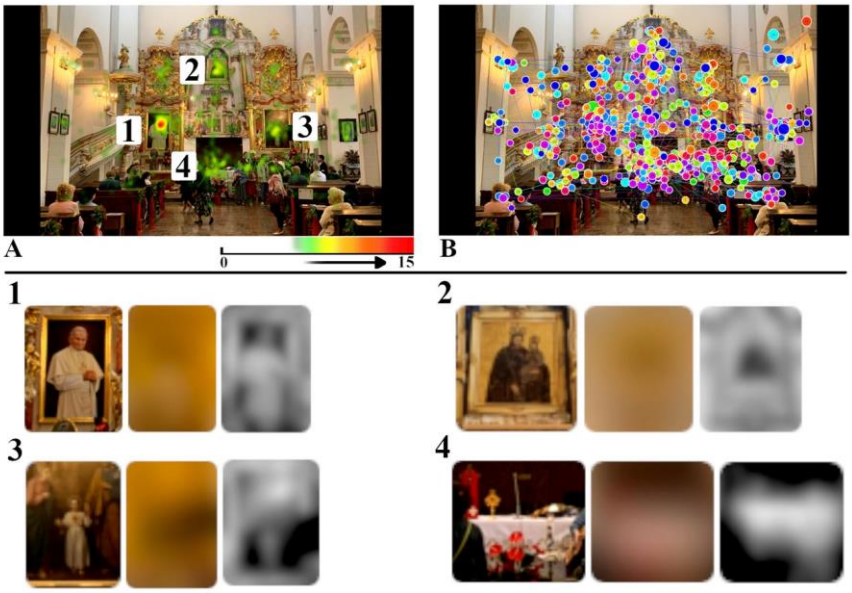

Fig. 13. Image number 8, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3, 4 – comparison of image fragments with intense fixation with the color hue and contrast level

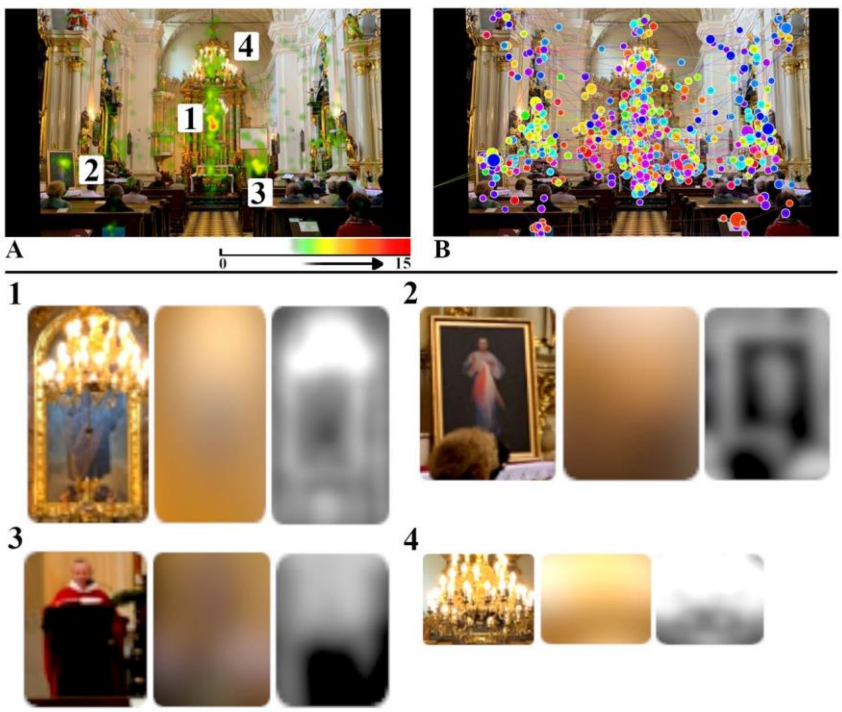

Fig. 14. Image number 9, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3, 4 – comparison of image fragments with intense fixation with the color hue and contrast level

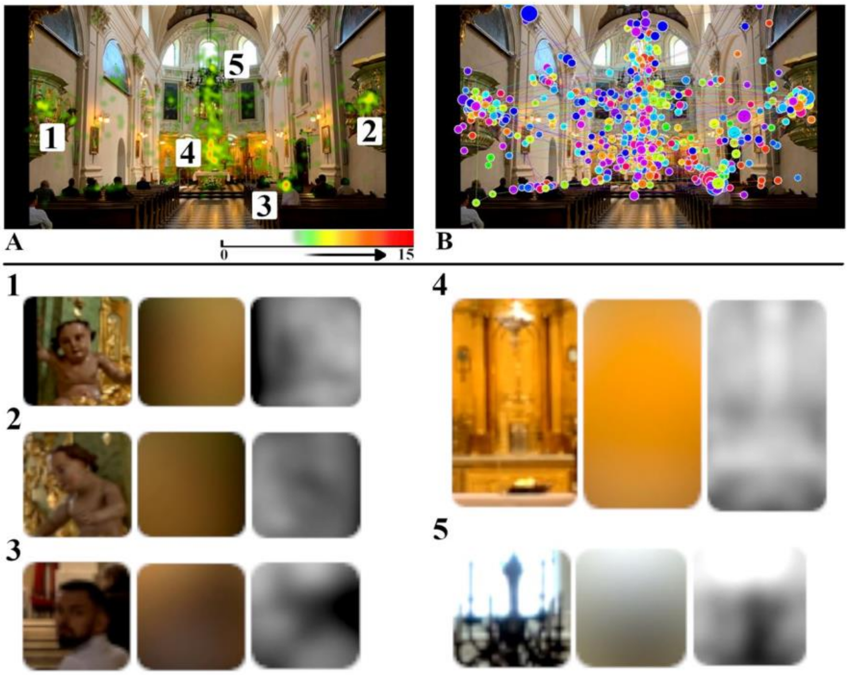

Fig. 15. Image number 10, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3, 4, 5 – comparison of image fragments with intense fixation with the color hue and contrast level

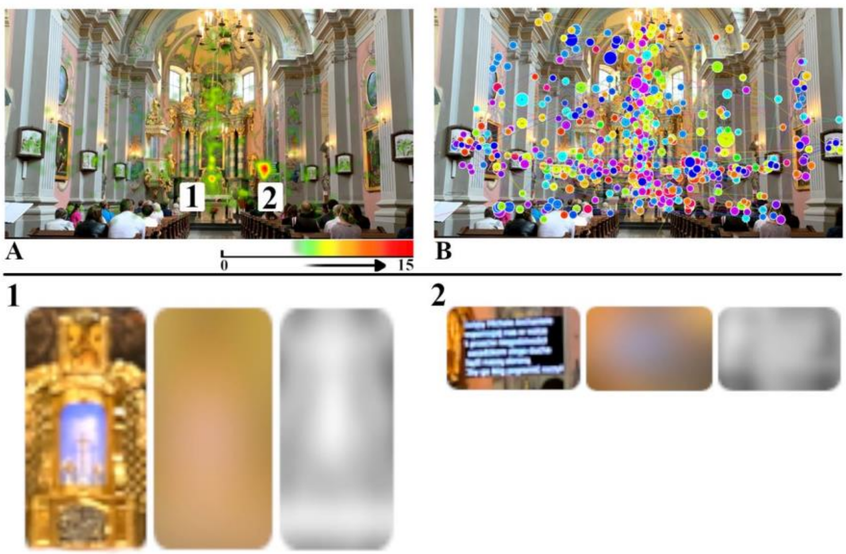

Fig. 16. Image number 11, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2 – comparison of image fragments with intense fixation with the color hue and contrast level

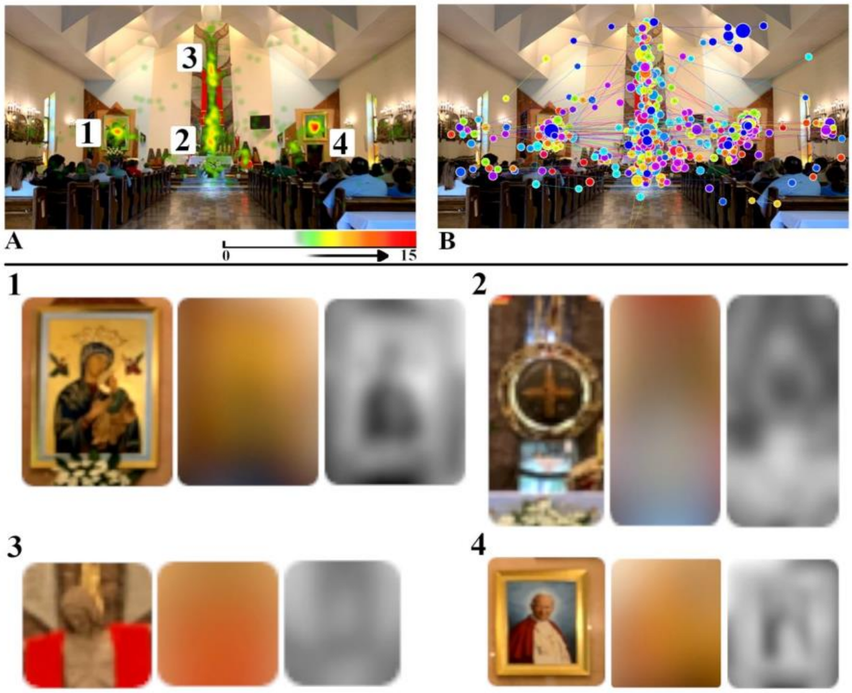

Fig. 17. Image number 12, A – results of heat map analysis, B – results of Gaze Plot analysis, 1, 2, 3, 4 – comparison of image fragments with intense fixation with the color hue and contrast level

Table 1. Table of various values analyzed in the study in terms of individual images and marked spots
* values for which a correlation of the results of individual analytical parameters in the field of fixation was detected

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1	**Image**	**Spot**	**Position**	**Contrast level**	**Color hue**	**Brightness level**	**Subject**	**IA [fpa]**	**TTFF [s]**	**FD [s]**	**PF [%]**
2	1	1	Left	Low	Cool	Light	Person	11	3.04	0.36	77
3	1	2	Center	High	Warm	Dark	Interior	11	0.21	0.25	100
4	1	3	Left	Medium	Warm	Light	Person	8	2.57	0.26	82
5	1	4	Right	Low	Cool	Light	Person	11	2.82	0.41	77
6	**Total**	**4**									
7	2	1	Left	Medium	Warm	Light	Person	10	2.89	0.36	56
*8**	2	2	Center	High	Warm	Dark	Interior	16	0.26	0.25	100
9	**Total**	**2**									
10	3	1	Center	High	Warm	Light	Interior	7	1.72	0.25	74
11	3	2	Center	Medium	Warm	Light	Interior	11	2.13	0.27	77
12	3	3	Right	High	Cool	Light	Interior	16	1.10	0.30	79
13	**Total**	**3**									
14	4	1	Left	High	Cool	Light	Interior	8	1.87	0.25	74
*15**	4	2	Center	Low	Warm	Dark	Person	16	0.69	0.27	95
16	4	3	Center	High	Warm	Light	Interior	11	0.99	0.30	79
17	4	4	Righ	Low	Warm	Dark	Person	5	2.71	0.32	36
18	**Total**	**4**									
19	5	1	Left	Low	Warm	Light	Person	6	1.45	0.27	49
20	5	2	Center	Low	Warm	Light	Interior	12	0.93	0.24	87
21	5	3	Center	Low	Cool	Dark	Interior	6	2.05	0.19	44
22	5	4	Right	Low	Warm	Light	Person	8	1.90	0.24	74
23	5	5	Left	Low	Warm	Dark	Person	5	2.47	0.21	26
24	5	6	Right	Low	Warm	Dark	Person	5	3.44	0.23	36
25	**Total**	**6**									
26	6	1	Left	Medium	Warm	Light	Person	6	0.34	0.29	100
27	6	2	Center	Medium	Warm	Light	Interior	20	1.88	0.25	77

1	2	3	4	5	6	7	8	9	10	11	12
1	**Image**	**Spot**	**Position**	**Contrast level**	**Color hue**	**Brightness level**	**Subject**	**IA [fpa]**	**TTFF [s]**	**FD [s]**	**PF** [%]
28	**Total**	**2**									
29	7	1	Center	High	Warm	Light	Interior	11	0.33	0.27	100
30	7	2	Center	High	Warm	Dark	Interior	8	1.86	0.33	67
31	7	3	Left	High	Warm	Dark	Interior design	5	1.77	0.26	79
32	**Total**	**3**									
33	8	1	Left	High	Warm	Dark	Person	16	1.05	0.29	82
34	8	2	Center	Medium	Warm	Dark	Person	7	2.60	0.30	62
35	8	3	Right	High	Warm	Dark	Person	9	1.93	0.25	59
36	8	4	Center	High	Warm	Dark	Interior design	6	1.17	0.21	82
37	**Total**	**4**									
38	9	1	Center	High	Warm	Light	Interior	12	0.92	0.30	97
39	9	2	Left	High	Warm	Dark	Person	7	1.84	0.30	46
40	9	3	Right	High	Warm	Dark	Person	7	1.96	0.33	64
41	9	4	Center	High	Warm	Light	Interior design	6	2.13	0.26	62
42	**Total**	**4**									
43	10	1	Left	Low	Warm	Dark	Person	7	2.51	0.22	67
44	10	2	Righ	Low	Warm	Dark	Person	7	2.88	0.32	72
45	10	3	Righ	Low	Warm	Dark	Person	10	2.16	0.43	44
46	10	4	Center	Low	Warm	Light	Interior	10	0.61	0.25	82
47	10	5	Center	High	Cool	Light	Interior	7	2.36	0.25	74
48	**Total**	**5**									
49	11	1	Center	Low	Warm	Light	Interior	11	1.58	0.25	74
50	11	2	Right	High	Cool	Light	Interior	15	1.71	0.32	64
51	**Total**	**2**									
52	12	1	Left	Medium	Warm	Dark	Person	14	1.99	0.27	82
53	12	2	Center	Medium	Warm	Dark	Interior	10	0.96	0.26	87
54	12	3	Center	Low	Warm	Light	Person	12	1.60	0.27	74
55	12	4	Right	Low	Warm	Light	person	17	1.89	0.29	82
56	**Total**	**4**									
		43									

Table 1 represents the following criteria which were used in the comparative analysis and comparison charts (Figs. 18-21):

- position divided into center, left and right,
- contrast level divided into low, medium and high,
- color level divided into warm and cool,
- brightness level divided into light and dark,
- subject divided into person and interior,
- maximum fixations count per unit area (IA expressed in fpa),
- mean time to the first fixation per area of interest (TTFF),
- mean fixation duration in AOI (FD),
- the percentage of participants that fixated at least once within an AOI (in %).

The highest values are marked in color in the table according to the charts below. The highest values of the indicators are the most important in research terms. They include the number of fixations per unit area (IA), the time to the first fixation, the fixation duration and the percentage of all participants who observed the area of interest. According to the charts, the highest IA indicators are marked in orange, the highest TTFF indicators in red, the highest FD indicators in green and the results in the PF scale in blue.

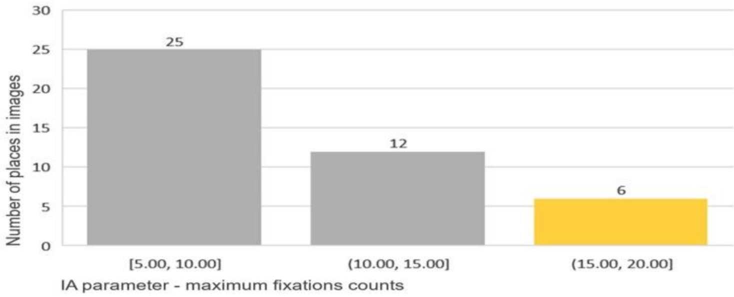

Fig. 18. A chart showing the result for the IA parameter – maximum fixations counts; for comparison, the highest parameters between 15 and 20 were selected and marked in orange in the table.

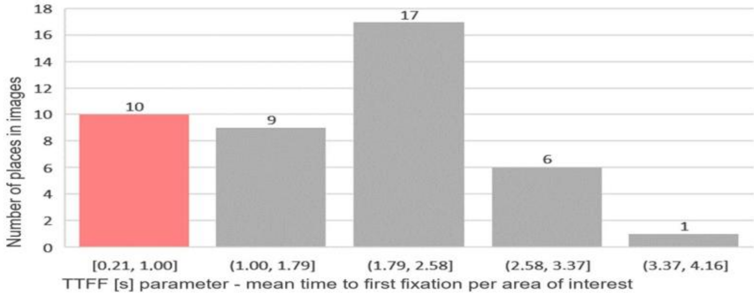

Fig. 19. A chart showing the result for the TTFF [s] parameter – mean time to first fixation per area of interest; for comparison, the shortest time between 0.21 and 1 were selected and marked in red in the table

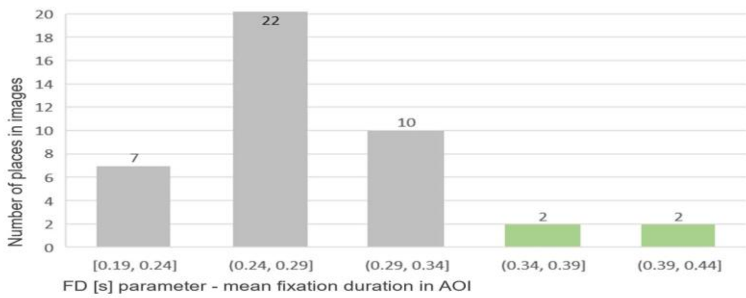

Fig. 20. A chart showing the result for the FD [s] parameter – mean fixation duration in AOI; for comparison, the highest parameters between 0.34 and 0.44 were selected and marked in green in the table.

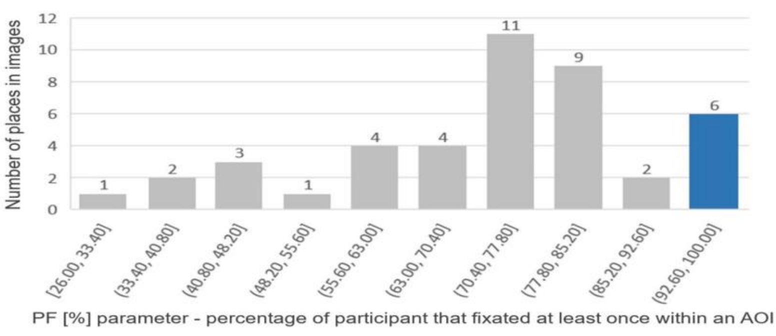

Fig. 21. A chart showing the result for the PF % parameter – the percentage of participants that fixated at least once within an AOI; the highest parameters between 92.60 and 100 were selected and marked in blue in the table.

The analysis of the successive 12 visual stimuli (images in Table 1) and review of the obtained results leads to some interesting observations.

In visual stimulus 1, the person sitting backward aroused relatively high interest in the subjects (8 fpa), even though the intensity of attention was lower than on the figures in the two paintings constituting the altar decoration (11 fpa). The average fixation duration on the faces of the subjects in the images was the longest, standing at 0.36 and 0.41 seconds.

In image 2, in addition to the central part of the altar, some subjects (56%) also focused on the image on the left side. In this case, there were long average fixation times (0.36 seconds) since the painting had lower contrast (medium) and darker colors.

In visual stimulus 3, respondents directed their attention the most quickly to the screen displaying text (1.10 s). The intensity of their attention (16 fpa) was also the highest among the other areas and the average fixation duration on this object was also the highest (0.36 s).

In image 4, with high intensity, respondents focused their attention on the figure of Christ (16 fpa) located in the center of the altar and the stained-glass window above the sculpture (11 fpa). Since these objects are located in the scene's center, they are localized first (0.69 and 0.99 seconds on average). Meanwhile, the painting placed to the right of the altar, noticed by only 36% of the observers, had the longest average fixation time. This is a consequence of this image being dark in tone, low in contrast and difficult to read.

In visual stimulus 5, the highest intensity of attention (12 fpa) was directed at the element of the altar furnishings – the golden chalice set in the scene's center. This element was the first to draw the attention of the study participants (0.93 s). The second, in terms of time (1.9 seconds) and intensity (8 fpa), was the face of the human sculpture set in the altar to the right.

Image 6 shows the interior of a modern church with a small number of elements on the altar. In the center, there is the Tabernacle. It attracted the strongest attention from all the elements in this scene and all the visual stimuli used in the experiment (20 fpa).

In image 7 there are no figures, both alive and in paintings, or figures in the form of sculptures. The respondents look the most intently at the central part of the scene (11 fpa), i.e., the table and the Tabernacle, which are the most intensely illuminated.

Despite its high number of details, the altar shown in visual stimulus 8 concentrated the highest intensity of attention (16 fpa) from study participants on the face of the figure in the picture on the left side altar. In addition, the study participants' attention was directed towards this image the fastest at an average time to the first fixation of 1.05 seconds. The second object with the lower intensity of attention (9 fpa) was the picture presenting three figures. In this case, the attention was mainly focused on the face of the child standing between his parents. The longest average fixation time occurred in the third image showing a figure painted in dark colors, which was located in the upper part of the altar.

In visual stimulus 9, the subjects' eyes were the most focused on the central area of the altar (12 fpa), where an image illuminated by the chandelier is suspended above it. The longest fixation duration occurred in the area of the face of the priest celebrating the mass (0.33 seconds).

Image 10 shows the church interior with a small number of people sitting in the pews. The persons at the altar are missing from these images. The participant's attention in the experiment is focused on the person facing the observer (10 fpa) and the central part of the altar (10 fpa). Although the average fixation duration was the longest in the area of the face of the person facing the observer (0.43 seconds), only 44% of the subjects turned their attention to this face. Looking at the times to the first fixation, the subjects directed their gaze sequentially to the center of the altar, the aforementioned man and then to the chandelier and the angel sculptures located on the pulpits to the left and right, close to the observer.

In visual stimulus 11, the respondents looked with the greatest intensity at the screen displaying white text on a black background (15 fpa), even though it is located to the right of the center point of the scene. The fixations in the screen area are characterized by a long average fixation time (0.32 seconds) signifying the respondents' focus on the displayed text.

In image 12, high focus intensity was on the figures located on the paintings placed on the sides to the left and right of the altar (14 and 17 fpa, respectively) and on the objects in the central part of the altar: the Tabernacle (12 fpa) and the figure of crucified Christ (10 fpa). These objects distributed the participants' attention so that not all of them attracted their gaze. For example, the figure of Christ was visually examined by 74% of the respondents.

Fixations last, on average, 0.2-0.3s [19]. They may be shorter or much longer. Various factors influence the fixation length. There are theories that available visual information influences fixation duration [20, 21]. Longer fixation times were observed for lower contrast levels and longer fixation times for grayscale scenes than for color scenes [22]. In this experiment, the exposure time of the stimuli was not long – it was 5 seconds. Average fixation length results were generally within the range reported above. There were also longer average fixations, but they did not exceed 0.41 s. The most common longer fixations were observed on the faces of figures of living people, but also on the faces of people in the paintings, or the faces of sculptures (e.g., images 1, 2, 4, 9, 10 and 11). This was because the respondents were interested in the person, or rather their face, or tried to recognize them or looked at them because they knew the face and they were important to them. In some cases, the fixation duration was clearly influenced by the dark colors of the objects or low contrast. The time to the first fixation on scene objects or areas of interest communicates the importance of these elements or areas and the way they were presented. Most often, the respondents started visual examination at the central point of the stimulus, as that is how they were positioned in relation to the monitor screen and because of the interior architecture of churches, where the altar is usually located at the focal point.

The data included in Table 2 and shown in the chart illustrates the relationship between the element's position, contrast level, color, brightness level and the visible element.

Table 2. The table provides a summary of the quantitative data

Position		Contrast level		Color hue		Brightness level		Subject	
Left	12	Low	17	Cool	7	Light	23	Person	22
Center	20	Medium	8	Warm	36	dark	20	Interior design	21
Right	11	High	18						

The relationship is observed in terms of the warm color, which may also indicate a correlation with light points whose color is kept in a warm shade. Warm light is characteristic of the interiors of religious buildings [23].

In terms of the location of the viewed element, a high level of the image center is visible. The center of the viewed photo is not only the geometric center but the perspective vanishing point. Moreover, in the center of the painting, there is an altar, which is the dominant form in the painting. The left and right positions of the photo were observed in an almost identical form by the experiment participants. This proves that during 5 seconds of observation, the human eye can analyze the image as a whole, confirmed by the correctly selected analysis time for each photo (Figs. 22 and 23).

The human focus maps, obtained by tracking 39 observers' eyes, were also used in the analyses. Focus maps are an alternative to heat maps. They are black and white and are the reverse of heat maps. They are a graphical representation of the gaze in the color spectrum from complete darkness to complete transparency [24]. The degree of transparency reflects the intensity of the examinee's attention directed towards a given element [7]. The intensity of attention may depend on the number or duration of fixations.

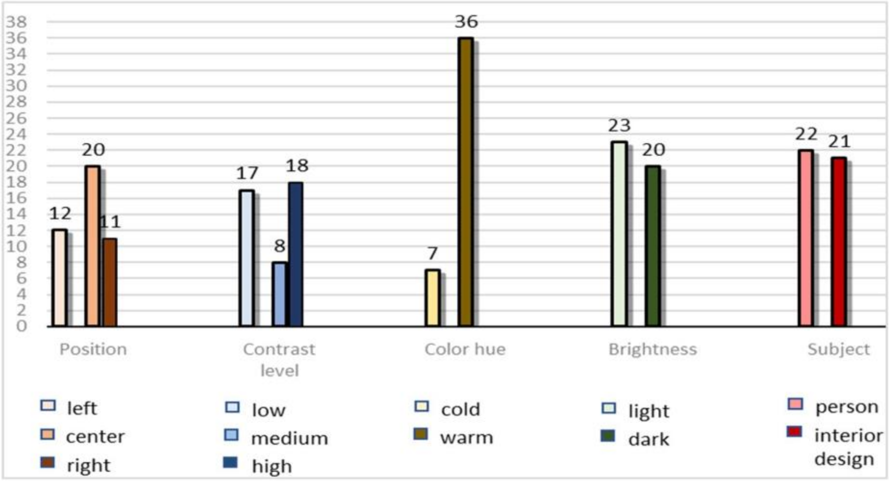

Fig. 22. A chart showing the relationships between the examined factors: position, contrast level, color hue, brightness and subject

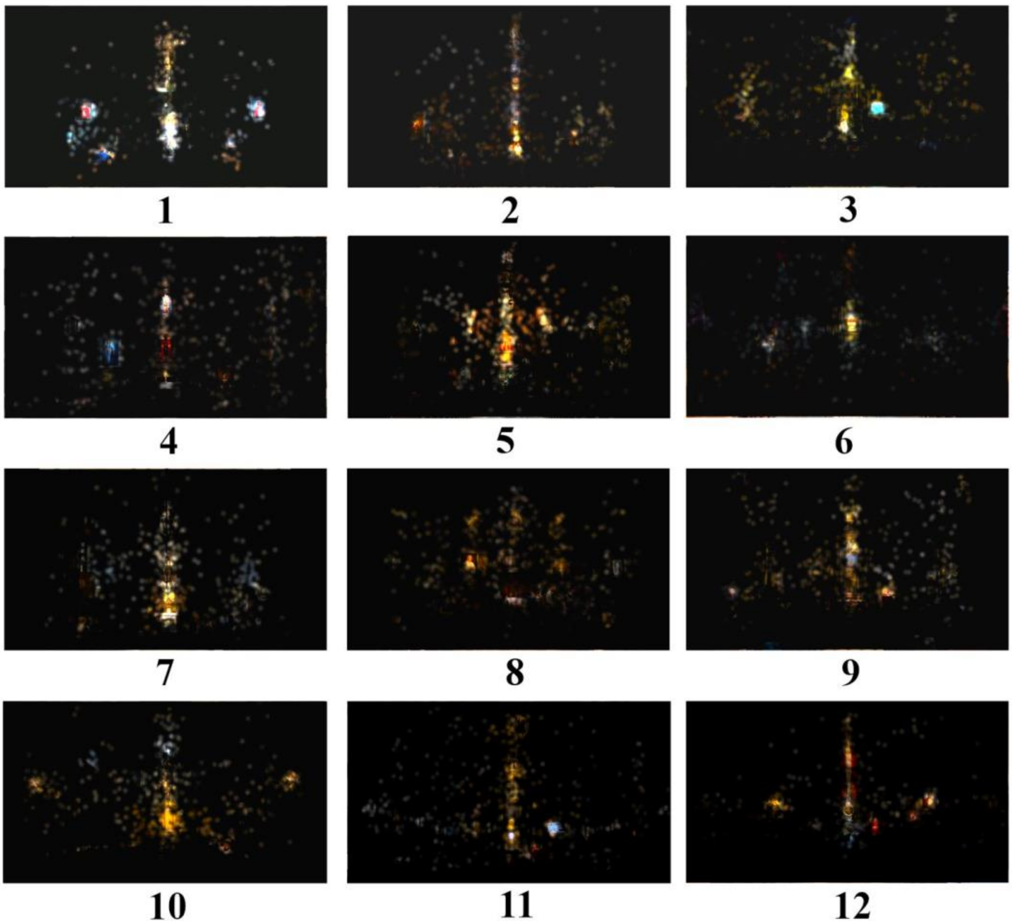

Fig. 23. Analysis of gaze opacity areas of interest – results

In figure 23 there are generated maps in which the level of attention intensity depends on the number of fixations. This type of visualization easily shows the areas that were noticed by the examined participants and those that were omitted. Many fixations lead to a clear vision of the visual stimulus. The gaze opacity analysis results conclude that the first and main element of observation is the central part of the photograph. It is necessary, however, to consider the correction of this phenomenon, which may be intensified by the central and single-angle view perspective. The analysis results also show the intensity of fixation around facial silhouettes.

In terms of the contrast level, an interesting aspect is the fact that the elements with the highest fixation have relatively high or – on the contrary – low contrast levels. The brightness level of the analyzed elements, tested in terms of the light and dark coefficients, remains at a similar level. Regarding the subject of things viewed in photos, this factor was divided into two dominant groups. These are silhouettes and faces of people as well as interior finishings. The group of silhouettes of people also includes those that are not people but representations of paintings or sculptures. The grouping is justified because the painting showing the person is realistic, just like the sculptures. These are not abstract or distorted representations, but realistically reproduced characters [25].

The central part is usually the most saturated place in terms of the number of fixations. It results primarily from the centrally placed altar in the main nave of the church and the two-way composition with the central point located in the altar. However, in research, the most important aspect is not so much the location of the focus of the eyes, but the object on which the viewer's eyes are focused. Among these objects, scientists are looking for connections between their subject matter, form, color and shape.

Below are elements that are neutral to human vision. Fixation on these areas was not recorded (Fig. 24).

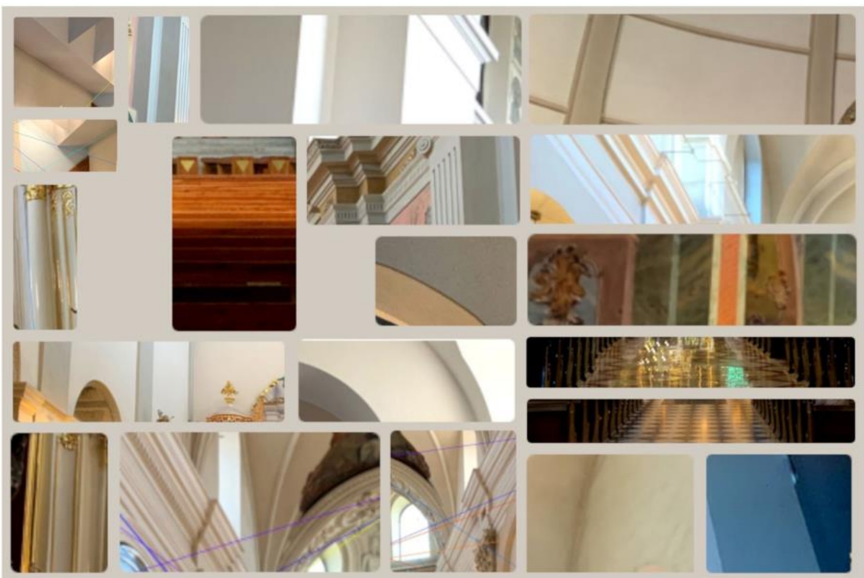

Fig. 24. Elements in the twelve examined photos of church spaces that the participants did not look at. These elements may be considered unattractive to the human eye and neutral in terms of interior design

In the study of characteristic elements found in the city of Macau, it was observed that the human eye first focuses on letter markings. Text is a source of information for humans, which may influence their visual sensitivity to numbers and letters [26]. The study also noted that the photos where text was included had been analyzed by most participants for a significantly long period. The experiment conducted with photos of altars also proves the thesis that the human eye first captures text appearing in space.

Conclusions

The results of the study experiment noticeably indicate that even though church interiors feature many architectural, decorative, interior-design and stucco elements, around 50% of the observations concerned human faces. The faces in the photos were a person or an image in a painting or sculpture. Text was the second element visible during the number of fixations. If the interiors were minimalist and the only elements were faces, the research results would be less reliable. However, in the study conducted, photos were deliberately taken to show dozens or hundreds of different elements. Despite such diversity, the 39 subjects focused their gaze significantly on facial images. In a comparative study of the target analysis, also performed using an eye tracker, we reviewed the individual spots on the face where the human eye focuses the most. Despite differences in image analysis between ethnic and age groups, the human face is an element that the human eye captures in the viewed space [27].

In Table 1, two values are marked with*. These are the most important of the study results; a correlation was observed between FC, TTFF and PF values. In the first value in line 8, the observation point is the priest and the monumental altar. In the second significant value, under 15, the area of observation is the monumental figure of Christ. These two areas are characterized by a central location, warm color tones and dark brightness levels. These two areas can be a reference point for shaping the strongest eye attractors in the interior.

The conducted research did not reveal any significant differences in terms of the number of fixations and the proportion of rooms. In order to investigate the properties of room proportions and their impact on the perception of space, it would be necessary to use a different type of research equipment in the form of eye tracking glasses and to conduct in situ tests in churches.

In the case of newly designed churches and sacred buildings, it is worth pre-analyzing the location of sculptures and paintings showing silhouettes of people. The study results show that the human eye looks for human faces and silhouettes in space [28]. Moreover, elements with a high degree of brightness, such as large chandeliers, also attract attention. These two factors can be designed and presented in sacred buildings differently, so humans do not detect these elements and the interior becomes more meditation-friendly. Concentration levels during prayer and meditation will be higher if there are no faces or silhouettes of people depicted in paintings or sculptures in the viewed space. It is recommended to design the interior lighting discreetly using small light fixtures enabling the interior to be uniformly filled with artificial light on the entire surface of the walls and ceilings. In terms of eye focus, large light fixtures are not recommended because they produce high contrasts and dominate the interior design. The results described in this paper are the first stage of the research. In the next one, the authors will present the results of an experiment involving the design of interiors without paintings, human-like silhouettes and human faces. The interiors will also include special interior lighting in which there will be no dominant, extensively lit areas. An important aspect of this paper is the results regarding the elements that focus the eyes and those that the participants did not observe. It can be considered that such architectural elements have a neutral character for human sight.

References

[1] W. Krauze, M. Motak, *Neurosciences in architecture. Applied research and its potential in architectural design,* **Teka Komisji Urbanistyki i Architektury Oddział PAN w Krakowie**, **50**, 2022, pp. 330-356. https://doi.org/10.24425/tkuia.2022.144856.

[2] K. Panetta, Q. Wan, A. Kaszowska, H.A. Taylor, S. Agaian, *Software Architecture for Automating Cognitive Science Eye-Tracking Data Analysis and Object Annotation,* **IEEE Transactions on Human-Machine Systems**, **49**(3), 2019, pp. 268-277. https://doi.org/10.1109/THMS.2019.2892919.

[3] G. Lio, R. Fadda, G. Doneddu, J.R. Duhamel, A. Sirigu, *Digit-tracking as a new tactile interface for visual perception analysis,* **Nature Communications**, **10**, 2019, pp. 1-13, https://doi.org/10.1038/s41467-019-13285-0.

[4] Y. Liu, Z. Zhou, Y. Xu, *Design Element Preferences in Public Facilities: An Eye Tracking Study,* **Land**, **12**(7), 2023, Article Number: 1411. https://doi.org/10.3390/land12071411.

[5] J.B. Hollander, A. Sussman, P. Lowitt, N. Angus, M. Situ, *Eye-tracking emulation software: a promising urban design tool,* **Architecture Science Review**, **64**(4), 2021, pp. 383-393. https://doi.org/10.1080/00038628.2021.1929055.

[6] W. Tuszyńska-Bogucka1, B. Kwiatkowski, M. Chmielewska, M. Dzieńkowski, W. Kocki, J. Pełka, N. Przesmycka, J. Bogucki, D. Galkowski, *The effects of interior design on wellness – Eye tracking analysis in determining emotional experience of architectural space. A survey on a group of volunteers from the Lublin Region, Eastern Poland*, **Annals of Agricultural and Environmental Medicine**, **27**(1), 2020, pp. 113-122. https://doi.org/10.26444/aaem/106233.

[7] A.B. Tobii, *User Manual – Tobii Studio. Version 3.2 Rev A*, Stockholm, Sweden, 2012

[8] A. Bojko, *Informative or Misleading? Heatmaps Deconstructed*, **Human-Computer Interaction. New Trends. HCI 2009** (editor: J. A. Jacko), Lecture Notes in Computer Science, 5610, 2009, Springer, Berlin, Heidelberg, https://doi.org/10.1007/978-3-642-02574-7_4.

[9] R.J.K. Jacob, K.S. Karn, *Eye Tracking in Human-Computer Interaction and Usability Research: Ready to Deliver the Promises*, **The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research,** (Editors: J. Hyona, R. Radach, H. Deubel), Elsevier Science, Amsterdam, 2003, pp. 573–605. https://doi.org/10.1016/B978-044451020-4/50031-1.

[10] K. Rayner, *Eye Movements in reading and Information Processing*, **Psychological Bulletin**, **85**, 1978, pp. 618–660. https://doi.org/10.1037/0033-2909.85.3.618.

[11] T.A. Salthouse, C.L. Ellis, *Determinants of Eye-Fixation Duration*, **The American Journal of Psychology**, **93**(2), 1980, pp. 207–234. https://doi.org/10.2307/1422228.

[12] S. Erslan, *Eye Tracking Scanpath Analysis Techniques on Web Pages: A Survey, Evaluation and Comparison,* **Journal of Eye Movement Research**, 9**(1)**, 2015, pp. 1-19. https://doi.org/10.16910/jemr.9.1.2.

[13] P. Huddleston, B.K. Behe, S. Minahan, R.T. Fernandez, *Seeking Attention: An Eye-Tracking Study of In-Store Merchandise Displays*, **International Journal of Retail and**

Distribution Management, **43**(6), 2015, pp. 561-574. https://doi.org/10.1108/IJRDM-06-2013-0120.

[14] A. Talukder, J.M. Morookian, S. Monacos, R. Lam, C. LeBaw, J.L. Lambert, *Eye-tracking architecture for biometrics and remote monitoring*, **Applied Optics**, **44**(5), 2005, pp. 693-700. https://doi.org/10.1364/AO.44.000693.

[15] B. Wąsikowska, *Eye tracking w badaniach mrketingowych*, **Zeszyty na ukowe uniwersytetu szczecińskiegonr 863, Studia Informatica**, **36**, 2015, pp. 177-192, https://doi.org/10.18276/si.2015.36-13.

[16] M.A. Rusnak, *Eye tracker jako prospołeczne narzędzie zarządzania dziedzictwem urbanistycznym I architektonicznym*, **Ochrona dziedzictwa kulturowego**, **9**, 2020, pp. 97-115, https://doi.org/10.35784/odk.1273.

[17] M. Lisińska-Kuśnierz, M. Krupa, *Suitability of Eye Tracking in Assessing the Visual Perception of Architecture—A Case Study Concerning Selected Projects Located in Cologne*, **Buildings**, **10**(2), 2020, Article Number: 20. https://doi.org/10.3390/buildings10020020.

[18] H.J. Rosas, A. Sussman, A.C. Sekely, A.A. Lavdas, *Using Eye Tracking to Reveal Responses to the Built Environment and Its Constituents*, **Applied Sciences**, **13**(21), 2023, pp. 3-25. https://doi.org/10.3390/app132112071.

[19] K. Rayner, *Eye movements and attention in reading, scene perception, and visual search*, **Quarterly Journal of Experimental Psychology**, **62**, 2009, pp. 1457–1506. https://doi.org/10.1080/17470210902816461.

[20] G.R. Loftus, *Picture perception: Effects of luminance on available information and information-extraction rate*, **Journal of Experimental Psychology: General**, **114**(3), 1985, pp. 342–356. https://doi.org/10.1037/0096-3445.114.3.342.

[21] S.K. Mannan, K.H. Ruddock, D.S. Wooding, *Automatic control of saccadic eye movements made in visual inspection of briefly presented 2-D images*, **Spatial Vision**, **9**(3), 1995, pp. 363-386. https://doi.org/10.1163/156856895X00052.

[22] W. Einhäuser; Ch. Atzert; A. Nuthmann, *Fixation durations in natural scene viewing are guided by peripheral scene content*, **Journal of Vision**, **20**(4), 2020, Article Number: 15. https://doi.org/10.1167/jov.20.4.15.

[23] J. Kim, N. Kim, *Quantifying Emotions in Architectural Environments Using Biometrics*. **Applied Sciences**, **12**(19), 2022, pp. 1-22, https://doi.org/10.3390/app12199998.

[24] B.S. Bagepally, *Gaze Pattern on Spontaneous Human Face Perception: An Eye tracker study*, **Journal of the Indian Academy of Applied Psychology**, **41**(3), 2015, pp. 128-131.

[25] P. Ugwitz, O. Kvarda, Z. Jurˇíková, C. Šašinka, S. Tamm, *Eye-Tracking in Interactive Virtual Environments: Implementation and Evaluation*, **Applied Sciences-Basel**, **12**(3), 2022, Article Number: 1027. https://doi.org/10.3390/app12031027.

[26] P. Wang, W. Song, J. Zhou, Y. Tan, H. Wang, *AI-Based Environmental Color System in Achieving Sustainable Urban Development*, **Systems**, **11**(3), 2023, Article Number: 135. https://doi.org/10.3390/systems11030135.

[27] D.J. Kelly, S. Miellet, R. Caldara, *Culture shapes eye movements for visually homogeneous objects*, **Frontiers in Psychology**, **1**, 2010, Article Number: 6. https://doi.org/10.3389/fpsyg.2010.00006.

[28] D.T. Guarnera, C.A. Bryant, A. Mishra, J.I. Maletic, B. Sharif, *iTrace: Eye Tracking Infrastructure for Development Environments*, **Proceedings of the 2018 ACM**

Symposium on Eye Tracking Research & Applications, ETRA'18, **105**, 2018, pp. 1-3, https://doi.org/10.1145/3204493.3208343.

Received: March 2, 2024
Accepted: September 5, 2024