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Visual Integration Relationship between Buildings and the Natural Environment Based on Eye Movement

Teng Fei [1,2,3,*], Yiqing Liu [1,2] and Jianchun Guo [3]

[1] School of Architecture, Harbin Institute of Technology, Harbin 150001, China; 20b334003@stu.hit.edu.cn
[2] Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, Ministry of Industry and Information Technology, Harbin 150001, China
[3] Architectural Design and Research Institute, Harbin Institute of Technology, Harbin 150001, China; guojianchun93@163.com
* Correspondence: feiteng@hit.edu.cn; Tel.: +86-0451-8628-1166

Abstract: In current architectural practice projects, the external visual image presented by many buildings ignores the interpretation of the environment and the local context, as well as the emotional feeling of people in visual cognition. At present, some indicators in the field of architectural design can be analyzed quantitatively, but the evaluation criteria related to vision remain in the stage of relying on experience and feeling so that the design result cannot be controlled accurately. This article reports the study of the influence of building distribution form and the ratio of the shorter side to longer side of building blocks (the S/L ratio) on the visual integration relationship between buildings and the natural environment, based on eye-tracker experiments. Six actual completed projects were chosen for evaluation in two experiments. This study uses eye-tracking recorded data to investigate the influence of two elements (the distribution of building blocks and the S/L ratio of building blocks) on the visual integration relationship of buildings and environment. It provides a theoretical approach that helps to improve architects' building-design practices when working in different natural environments.

Keywords: visual expression; integration; distribution of building blocks; the ratio of the shorter side to longer side of building blocks; eye-movement experiment

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1. Introduction

The relationship between building and the natural environment has always been a popular issue in the construction industry. In recent years, with the improvement of people's living standards and aesthetic tastes, the lifestyle attitude of returning to nature has become the goal that people pursue. Therefore, an increasing number of rural buildings have emerged to meet people's spiritual needs. The visual expression of a building in the natural environment has become the focus of scholars, and a large number of studies concerning the function and form of architectural space, as well as the relationship between the material and colour of the building's façade and the natural environment, have also emerged in the specialized field of building [1]. However, there are still some shortcomings in today's architectural practices, such as too much attention to images and the pursuit of individuality, which lead to visual separation between building and the environment, and the cointegration of visual images caused by far-fetched collocation and the application of architectural language. Most of the current research on visual expression focuses on perceptual cognition, with few objective studies on the visual cognition process supported by data. Therefore, this study tries to explore the visual integration relationship between buildings and their natural environment through eye-movement behaviour capture.

2. Literature Review

2.1. Relationship between Visual Perception and Architectural Representation

Visual perception studies the physiological behaviour of vision and the cognitive behaviour in which the vision interprets and judges information when it is received [2]. Light is reflected from an object through the lenses of the eye to reach the retina. Then rod and cone cells are stimulated to release split-second chemical reactions converting the light to electrical impulses. After that, electrical impulses are transmitted to the brain. Finally, they are interpreted in the visual cortex and influenced by emotions, experiences, and habits of mind [3]. Visual perception is one of the most important feelings when people collect and feedback on external information. Currently, many studies on architectural expression are based on the theory of visual perception. Through the review of previous literature, the theory of visual perception has long been applied in the design strategy of regulating the relationship between building and the environment. At first, Arnheim [4] believed that the perception of vision is a process in which the cerebral cortex converts visual stimuli into an organized whole, namely, the physiological force pattern, according to certain rules. Related studies have been increasing year by year, for example, the studies by A. Sussman and J. B. Hollander [5], H. Ogce et al. [6], and M. Jiang et al. [7] (Table 1). They proved that the relationship between building and the environment could be studied based on the principle of visual perception.

Table 1. Literature review of the relationship between visual perception and architectural representation.

No.	Title	Author	Year	Research Content
1	Art and Visual Perception: A Psychology of the Creative Eye	R. Arnheim	1974	This book explores 10 aspects of vision in art: balance, shape, form, development, space, light, color, movement, tension, and expression. Applying Gestalt psychology to the analysis of visual art, this paper offers many valuable insights.
2	Cognitive Architecture: Designing for How We Respond to the Built Environment.	A. Sussman, J. B. Hollander	2021	This article summarizes the analysis of several architectural cases and outlines the CA (Cognitive Architecture) principles, which illustrate how humans adapt to the built environment from a cognitive perspective.
3	Visual impact assessment of the Istanbul Land-wall.	H. Ögçe, H. Müderrisoğlu, and S. Uzun	2019	This article takes 24 different photographs and examines the reactions to them by an expert and a public sample group. After that, they evaluate the visual impact of the Istanbul Land-wall and contribute to future design/planning stages.
4	Effects of different landscape visual stimuli on psychophysiological responses in Chinese students.	M. Jiang, A. Hassan, Q. Chen, and Y. Liu	2019	This article examines the physiological (electroencephalography (EEG)) and psychological (the semantic differential method (SDM) and State–Trait Anxiety Inventory (STAI)) responses of adults viewing different landscape pictures. They find out that different landscape pictures have psychophysiological relaxation effects on adults.

Observations were made on the different visual-perception behaviours formed by the stimulation of a specific psychological state and product in the minds of participating observers. These identifiable visual-perception behaviours were used to provide scientific data to support an analysis of the psychological activities in the minds of participating observers. These experimental observations enable us to establish a connection between human visual perception and architectural visual performance. They also made it possible for us to conduct in-depth research on the relationship between a building and its surrounding environment from the perspective of visual perception (in cognitive psychology).

2.2. Visual Integration between Building and the Natural Environment

The visual representation of buildings and the natural environment is the focus of this research. The relevant research in architecture has always been from the perspective of theory and practice. From the landscape style of English gardens in the late 18th century to the Arts and Crafts Movement in the late 19th century [8], the relationship between building and the natural environment has been gradually considered by architects. After the 1930s, architects criticized the "international style" in which building was visually detached from the environment and focused more on the visual integration between building and the natural environment [8]. Until the 1970s, the research theory in this field gradually became thorough and systematic [7]. McHarg [9] explained the close relationship between man and nature in his book *Design and Nature*, which put forward a planning approach based on ecological concepts. Hasegawa [10] believes that both humans and buildings belong to the Earth's ecosystem, and the building is a kind of man-made natural scenery. Kuma et al. [11,12] proposed in his two books, *Negative Architecture* and *Anti-Shape—Architecture Connected with Nature*, that buildings should not be separated from the environment but should reconcile the two and make people feel the warmth and softness of the building. In his book *Anti-Architecture*, Ito [13] subverted the conventional understanding of building, such as functionalism, and pointed out that building was the medium of coordination between humans and the natural environment. These architectural views with oriental aesthetic thoughts enrich the theoretical system of architectural creation in the natural context and promote the dynamic development of architectural practice toward a more sustainable direction. At present, how to better integrate buildings and the natural environment from the perspective of visual expression still needs further research. However, most of the previous related studies were from the perspective of theory and lacked objective discussion from the perspective of experiments. Objective experiments can provide more scientific and specific data, and the visual integration effect of building and the natural environment can be evaluated more accurately and rationally through experiments. Therefore, it is of positive and profound significance to supplement the research on the visual integration relationship between buildings and the natural environment from the perspective of experiments.

2.3. Factors Influencing the Visual Representation of Building in the Natural Environment

Regarding the visual performance effect of building in the natural environment, relevant scholars mostly study the material, colour, and structure of building in the natural environment from the perspectives of perception, humanity, and technology. Such books include *The Eyes of the Skin* [14], *Atmosphere* [15], and *Materials, Forms, and Architecture* [16]. There is no doubt that these studies are important, but the architectural form is also important for visual expression. Firstly, through literature research, this article found that the building block's proportions and the building block's distribution greatly impact the building's visual expression. For example, studies by T. Hamlin [17], F. K. Ching [18], Y. Y. Ren [19], and others (Table 2), have argued for the importance of these two factors on the visual expression of buildings. Secondly, the studies by Y. Chen [20] and T. Yu et al [21] (Table 2) further argue that the distribution of the building has a great influence on the visual expression of the building. Once again, analyzing the literature on architectural proportions, we found the studies focus on the relationship between the height and width of building outline. For example, J. R. Zhou [22] (Table 2) analyzed the ratio of the diagonal of the building block to the bottom edge of the building, Z. Zhao [23] (Table 2) analyzed the relationship between the height of waterfront building groups and the waterfront line, and J. D. Rounds [24] (Table 2) analyzed the height-to-width ratio of buildings. Although they describe the objects of study differently, they are all attempting to describe the relationship between the length-to-slenderness ratio of buildings. Therefore, this article identifies the study of building proportions by examining the length-to-slenderness ratio of the building block.

Table 2. Literature review of factors influencing the visual representation of building in the natural environment.

No.	Title	Author	Year	Research Content
1	*Forms and Functions of 20th Century Architecture: The Principles of Composition*	T. Hamlin	1952	The principles of architectural beauty (unity, balance, proportion, scale, rhythm, character, style, etc.) are used to explain the connotations of architectural beauty and the relationship between structure, materials, and architectural form.
2	*Architecture: Form, Space and Order*	F. K. Ching	1996	This article uses drawings to show the relationship between the basic elements of buildings. Exploring relationships between points, lines, planes, volumes, and other elements, it summarizes the regularity of architectural form, space and order and reflects the intention of studying architectural form in relation to principles of morphology.
3	*The research on the evaluation of visual environment quality of vernacular landscape in Guanzhong region based on behavioral psychological preference*	Y. Y. Ren	2019	This article analyzes the influence of vernacular buildings on the visual environment of the natural landscape in the Guanzhong region from the perspective of behavioral and psychological preference. It uses Analytic Hierarchy Process analysis to determine the influence of the distribution, layout, color, and material of the building on the visual environment, based on which we propose a renovation design strategy for the distribution and layout of the building.
4	*The research on the visual order of building plan layout form and street building space*	Y. Chen, H. M. Yan	2021	Based on the correlation between building layout and the visual order of street building space, this paper points out the critical influence of building layout on the visual order of street building space and proposes corresponding design strategies.
5	*Research on the iconic creation strategy of architectural clusters based on visual-perception theory*	T. Yu	2019	Through investigations, this article studies people's visual perceptual elements in architectural clusters. Then it clarifies and analyses the relationship between the figure base and architectural creation. Finally, it proposes a design approach that should be based on the function, scale, and environment of the architectural cluster.
6	*A study on the control of architectural group contours in the context of mountains with visual perceptual preferences*	J. R. Zhou	2018	This article uses photographs as samples to explore the relationship between public preference and quantitative control indicators of building complex contour lines in a mountain context. It is found that five quantitative control indicators have a strong influence on the value of public preference, and they are suggested as a single quantitative control indicator affecting the value of public preference, and design strategies are proposed accordingly.
7	*Research on building-height control planning around urban parks based on sightline analysis*	Z. Zhao	2013	This article uses the line of sight analysis method to analyze the proportion of waterfront buildings in terms of three elements: view characteristics, sight distance characteristics and building shading relationships. It proposes a method of height control for waterfront buildings so that the buildings in a waterfront environment may have a better visual effect.
8	*Using posterior EEG theta band to assess the effects of architectural designs on landmark recognition in an urban setting*	J. D. Rounds, J. G. Cruz-Garza, and S. Kalantari.	2020	This article developed a research platform using a virtual environment and electroencephalography (EEG) to better understand the neural processes associated with landmark usage and recognition during urban navigation tasks. It found that highly salient architectural features—those that contrast sharply with the surrounding environment—are more likely to attract visual attention, remain in short-term memory, and activate brain regions associated with way-finding when compared with non-salient buildings.

2.4. Eye-Movement Behaviour and Architectural Visual Representation

The eye-movement system is closely related to visual perception. Since most people's behaviour and activities cannot be separated from visual perception, eye movement can provide an effective information source for relevant research. Eye movements are now widely used to study information processing tasks, such as reading, scene perception, and visual search. In scene perception and visual search, the fixation time, fixation track, and the number of fixation points observed by eye-trackers have become important indicators for research. The observation and analysis of eye movement using eye-tracking in the West began in Arabia in the 10th century [25]. Al-Haytham [26] wrote the world's first physiological optics book, *Kitabal al Manazir* [27], which mainly introduced the structure of the eye and the visual system from the perspective of anatomy [27]. The study of eye movements remained dormant until the 19th century when eye-movement experiments began to develop again. Bell and Müller [28], founders of modern physiology, developed the field of eye-movement research by carrying out an accurate analysis of the individual's characteristics [28]. In recent decades, many scholars have studied eye-movement behaviour. Eye-movement tracking has been widely used in the visual evaluation of graphic and advertising design to measure the allocation of visual attention to stimuli [29], as in the studies by J. H. Choi et al. [30], H. Liu [31], Z. Zhang [32], and L. Zhang [33] (Table 3). Observing eye-movement behaviour with eye-trackers can quantify visual cognition, generate quantitative data of individual visual fixation behaviour, evaluate the rational factors behind visual behaviour, and explain how visual representation under various architectural organization principles could act on people's psychological world [34]. Therefore, it is of great significance to study the visual performance of buildings in the natural environment through eye-trackers.

Table 3. Literature review of eye-movement behaviour and architectural visual representation.

No.	Title	Author	Year	Research Content
1	*Investigation of human eye pupil sizes as a measure of visual sensation in the workplace environment with a highlighting colour temperature*	J.-H. Choi	2016	This article analyzed the impact of lighting colour temperature on visual perception in the working environment through experiments on pupil size.
2	*Study on Natural Light and Shadow Control in Sports Field Area Based on Eye-Tracker Experiment*	H. Liu	2014	This article used an eye-tracker to analyze the user's comfort with natural light and shadow in sports venues and proposed a new design strategy.
3	*Study on Interface Form of Urban Road Building*	Z. Zhang	2017	This article used an eye-tracker to explore the motivation of subjects when choosing an urban road–building interface.
4	*Study on Planning and Design of Forest Recuperation Footpath in Beijing Area*	L. Zhang	2019	This article analyzed the visual preferences and needs of users through eye-trackers and proposed a planning strategy for forest-rehabilitation trials in Beijing.

In summary, this paper takes the visual integration relationship between the buildings and the natural environment as the research object based on cognitive psychology. Using eye-movement experiments, we collected objective eye-movement data on people's observations of real pictures. The data was statistically analyzed to explore the influence of architectural distribution form and the slenderness ratio of building blocks on the visual integration relationship between nature and buildings (as shown in Figure 1). Responsive design strategies and techniques were then proposed for consideration by interested architects.

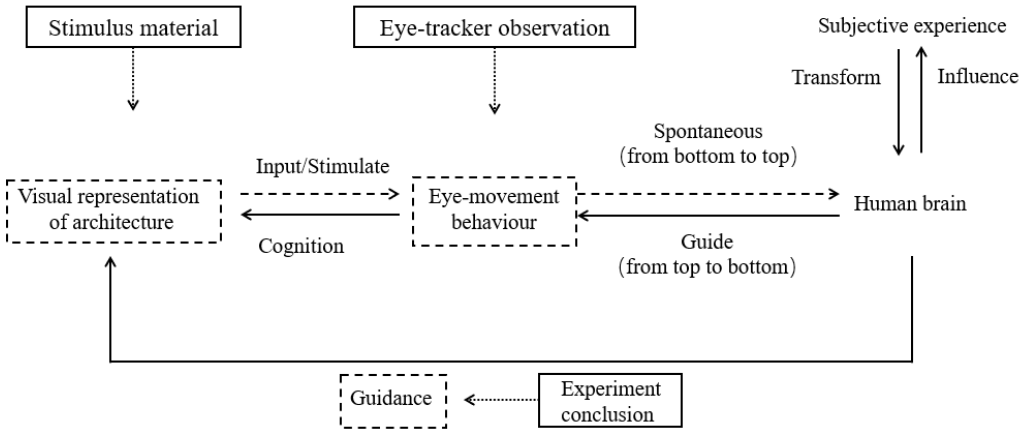


Figure 1. Experimental schematic diagram.

3. Research Design

3.1. Research Object

3.1.1. Cases

There are some differences between architectural renderings and real pictures of construction projects. To beautify the architectural image, the scenery of renderings is often artificially adjusted, so it is challenging to present the building site's environment directly. In other words, the actual environment or the surrounding scenery as shown in the graphic rendition of the building and its surrounding scenic ambience may not be a totally reliable picture of the natural scenery in which the building stands. In addition, the texture of building materials, the light and shadow of building blocks, and building details are also difficult to present accurately through graphic renderings. Furthermore, due to the different levels and the variable quality of rendering technology, the visual effects that different architectural renderings express are different, a factor which will affect experimental results. Different mapping levels could bring about cognitive differences among observers, thus affecting the eventual experimental results. Therefore, using architectural renderings as experimental observation cases may be somewhat misleading. To ensure the objectivity and accuracy of the experiment, actual pictures of the construction project were selected in this experiment.

Before doing the eye-tracking experiment, the experimental sample underwent a pre-processing work. Firstly, this study searched the Gooood website (a website that presents many building projects) for all completed building projects from 1 January 2000–1 April 2018. Secondly, selecting 20 building projects that suit the purpose of this study as a sample. The building projects selected share the following characteristics: (1) completed building projects, (2) the buildings are in a natural environment, (3) the purpose of the building design is to enhance the environmental quality, (4) the building blocks are simple, and (5) the building materials have similarities to the local environment's natural elements. Third, analyzing these 20 samples found that the form of building blocks could be categorized as D-1, D-2, and D-3 (Table 4). And the S/L ratio of building blocks was between 10% and 40%, which could be categorized as R-1, R-2, and R-3 (Table 5). Finally, using 20 samples, this study devised a questionnaire to select six samples with the most typical characteristics for the eye-movement experiment (Appendix A).

Table 4. Criteria of the distribution of building blocks.

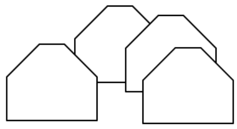
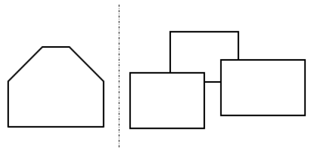
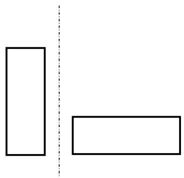
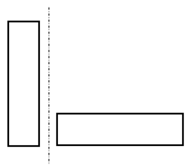
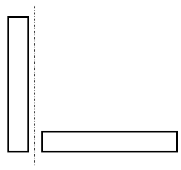
Variable	D-1	D-2	D-3
Definition (the distribution of building blocks)	Multiple polygonal blocks	Multiple rectangular blocks/One polygon block	One rectangular blocks
Illustration			

Table 5. Criteria of the S/L ratio of building blocks.

Variable	R-1	R-2	R-3
Definition (the S/L ratio of building blocks)	31–40%	21–30%	11–20%
Illustration			

Through a comprehensive analysis of survey results, the survey found that subjects were deeply impressed by six real photos and considered them of representative research significance for this experiment. Therefore, these six real photos were selected as experimental subjects in this study and were divided into two groups of experiments. In the first group of experiments, sample 1 is the Xitang Garden Resort Complex Project in Shangyunshang, sample 2 is the Yangshuo-Alila Sugar Factory, and sample 3 is the Liyuan Library. The views of these photos are all from human viewpoints, and the buildings are all at the center position of the pictures. The environmental elements of the building site are water, green plants, and sky. The distribution of buildings in sample 1 is relatively scattered. The two monomer buildings in sample 2 are complete in shape but far away from each other, and the distribution form of these buildings is between dispersed and concentrated. The distribution of buildings in sample 3 is relatively concentrated. According to the numerical analysis of the H (hue), S (saturation), and B (brightness) colour mode and the analysis of the picture composition proportion of the site environment, the three samples of the first group have similar colour compositions of the site environment. In terms of colour, the H of sky samples 1 and 2 is blue, the S is moderate and the B of the three samples is significantly different. The water surface can be divided into two types, both of which exist in the three samples. The H on the water surface is blue–green, and the B and S are similar. The H on the water surface is blue, and the B and S of samples 2 and 3 are similar. The H of the plant part is green, and the B and S are similar (as shown in Table 6).

In the second group of experiments, sample 4 is Anaya Library, sample 5 is Anaya Church, and sample 6 is the Black Tent Travel Camp Center. The views of these photos are all human viewpoints, and buildings are all at the center position of these pictures. The environmental components of the site where the building is located are mainly composed of sky (blue), ground (yellow), and water (blue). In terms of composition proportion, the blue part plays a dominant role in the site environment, occupying two-thirds of the whole image. The yellow part is of secondary importance in the site environment, occupying one-third of the whole image. Buildings in the second group of samples are all single buildings with similar interface materials and solid colours, which are different from colours of the site environment. This paper draws on Yoshinobu Ashihara's study of the scale of external space (using the distance D between people and buildings and the height H of buildings to describe the visual perception of external space) to analyze the relationship between the base of a building in its natural environment [35]. Based on this, this paper uses the ratio of the shorter side (S) to the longer side (L) of the building's main facade to describe the visual characteristics of the building (the S/L ratio) in order to describe the visual centrality of the building accurately. Buildings in sample 4 are relatively square, with the S/L ratio of approximately 33%. The building in sample 5 is a triangle. According to the visual dynamics, the shape has an upward dynamic force, and its S/L ratio is approximately 25%. Buildings in sample 6 are structured with the S/L ratio of approximately 15%. According to HSB colour model numerical analysis and picture composition proportion analysis of the site environment, the colour composition and proportion of these three samples in the second group are similar. In terms of colour, the sky H is blue, the S is similar, and the B differs greatly. The H of the ground is yellow, and the S and B are similar (as shown in Table 7).

Table 6. Picture analysis of the first group of experimental subjects.

Sample		**Sample 1**	**Sample 2**	**Sample 3**
Buildings		Yunshang Xitang pastoral resort complex	Yangshuo–Alila Sugar Factory	Liyuan Library
Photos				
Experimental sample building block				
Viewpoint		Human viewpoint	Human viewpoint	Human viewpoint
Location		Guangdong	Guangxi	Beijing
Function		Reception center	Hotel	Library
Area		500 m^2	315 m^2	275 m^2
Floor		2	2	2
Elements of natural environment	Sky	Have	Have	Have
	Green plants	Have	Have	Have
	Water	Have	Have	Have
Building	Position in photo	Center	Center	Center
	Criteria of the distribution of building blocks	D-1	D-2	D-3
Sky colour analysis	H	214	217	0
	B	86	84	0
	S	5	23	100
Colour analysis of water 1	H	198	25	38
	B	54	57	49
	S	53	44	68
Colour analysis of water 2	H	125	124	124
	B	49	24	25
	S	35	27	24
Plant colour analysis	H	166	157	141
	B	13	20	34
	S	66	32	20

Table 7. Picture analysis of the second group of experimental subjects.

Sample		**Sample 4**	**Sample 5**	**Sample 6**
Buildings		Anaya Library	Anaya Church	Black Tent Travel Camp Center
Photos				
Experimental sample building block				
Viewpoint		Human viewpoint	Human viewpoint	Human viewpoint
Location		Hebei	Hebei	Xizang
Function		Library	Church	Museum
Area		500 m^2	270 m^2	600 m^2
Floor		2	2	1
Elements of natural environment	Sky Ground Water	2/3 1/3 Have	2/3 1/3 Have	2/3 1/3 None
Building	Position in photo Physical distribution Criteria of the S/L ratio of building blocks	Center Cuboid R-1 (33.33%)	Center Cone R-2 (25.00%)	Center Cuboid R-3 (15.43%)
Sky colour analysis	H B S	206 95 63	205 81 51	204 58 51
Ground colour analysis	H B S	22 79 49	25 57 44	38 49 68
Water surface colour analysis	H B S	202 66 48	202 66 48	/ / /

3.1.2. Subjects Selected

As this experiment is of a certain professional level, college students with a certain architectural professional background were selected to participate in the experiment. The total number of subjects was 35, of which 29 were effective samples, and the male-to-female ratio was 16:13. The visual acuity was normal after a naked vision or visual correction.

3.2. Research Methods and Procedures

The purpose of most eye-movement studies is to identify and analyze the visual attention patterns of individuals while performing specific tasks, such as reading, searching, viewing images, and driving [36]. This experiment mainly observes the eye-movement behaviour of the static object when the subject's head remains stationary. In this experimental model, the main eye-movement behaviours of subjects were saccades and fixation. Saccade reflects the changing track of eyeball movement and the change in fixation position [37]. During each saccade, visual acuity was suppressed, making it difficult to see the image clearly. Therefore, visually, the world can be perceived only through fixation [38].

3.2.1. Fixation Time Experiment

Tobii Studio can measure how long the human eye continues to gaze at an area and the fixation time of first entering a certain area. According to the principle of visual attention, visual accuracy deteriorates rapidly when the eye moves away from the central area of the visual field. Therefore, people will gaze at a specific area for longer when this area is of interest or challenging to understand. When viewing stimulus materials, people would first rely on implicit attention to determine the part of the visual field that needs attention and then turn their eyes away [39]. Therefore, the degree of attractiveness of an area can be judged according to the duration of gazing at it. The visual salience of an area can also be judged according to the time of the first entry fixation. The visual expression effect of building in the environment was further analyzed through these two indicators.

3.2.2. Fixation Track Experiment

The fixation trajectory map provides the information on the observation sequence and the detailed information on individual fixation, which can be used to analyze the behaviour pattern of the subject. In the fixation trajectory map, the line segments connect each pair of adjacent fixations, and the multi-segment lines formed by multiple line segments reflect the eye-movement track of the observed sample [34]. Experiments have proved that, among many types of saccade behaviours, a backward-looking saccade is a form of eye movement used to process contrasting information. More backtracking behaviour occurs in two different interest regions, which means a stronger information correlation between these two regions [34]. The site environment area and the building area in the sample were divided into different AOI (Area of Interest) selections, and the relationship between the building and the environment was studied by counting the lookback behaviour between different areas.

3.2.3. The Number of Fixation Points Experiment

The fixation is a basic output measure of interest, showing what the eye is looking at. In terms of spatial distribution, these fixations indicate how much the subject regards different areas of the sample. The number of fixations in different sample areas can also mean the subject's comprehensive degree of information search in this area. According to these two factors, subjects' attention to buildings in different environments was further analyzed.

In this experiment, a Tobii_T60XL (producer: Tobii, location: Stockholm Sweden) eye-tracker was used to record subjects' eye-movement data when viewing different pictures, and Tobii Studio 3.1 data analysis software was used to complete the data analysis. Before the test, its purpose was briefly introduced to each subject. During the test, the observation duration of each sample was 8 s, and there were six test stimulus materials in total. To avoid the cross-influence of stimulus materials, blank pages were presented for 5 s before playing each sample, and the total duration of the experiment was 1–2 min. None of the subjects selected for this paper had been familiar with the architectural sample in advance (Figure 2).

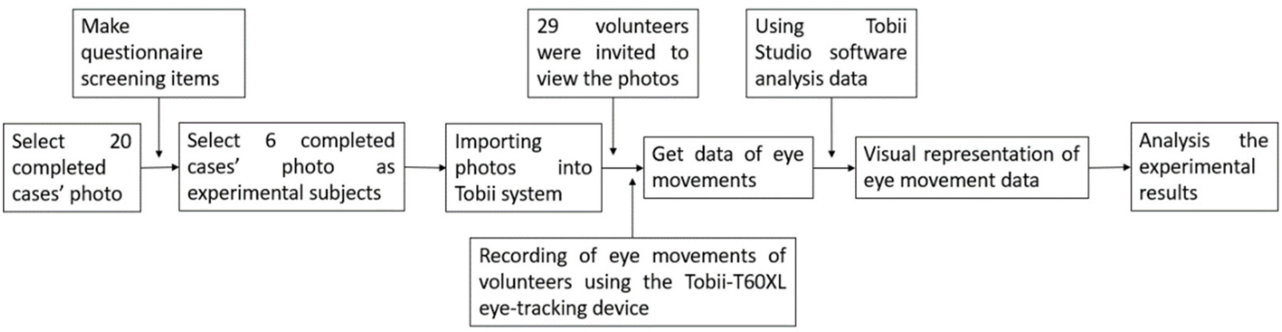


Figure 2. Flow chart of experimental design.

4. Results

4.1. Analysis of the Visual Attraction of Building Based on Fixation Time

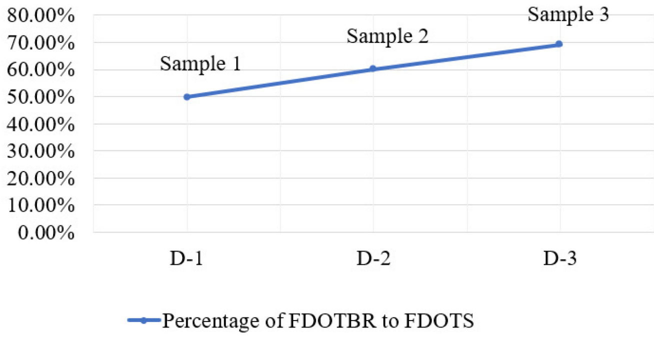
The site environment area and the building area in the first group of experimental samples were divided into different AOI selections for analysis. The relevant fixation time data of the site and the building were detected, and the results are shown in Figure 3. In the figure, the rectangle of two regions is the residence time of the subject's sightline observed by the eye-tracker in the sample photo. In contrast, the polygon region is the residence time of the subject's line of sight observed by the eye-tracker in the building selection in the sample photo. In sample 1, fixation duration on the sample (FDOTS) of subject 3 was 7.41 s, and fixation duration on the building region (FDOTBR) was 3.56 s. FDOTS of subject 6 was 7.45 s, and FDOTBR was 3.47 s a. FDOTS of subject 16 was 7.57 s, and FDOTBR was 3.98 s a. In sample 2, FDOTS of subject 3 was 7.24 s, and FDOTBR was 4.94 s. FDOTS of subject 4 was 8.03 s, and FDOTBR was 5.69 s. FDOTS of subject 15 was 7.79 s, and FDOTBR was 4.60. In sample 3, FDOTS of subject 1 was 7.46 s, and FDOTBR was 4.52 s. FDOTS of subject 3 was 7.24 s, and FDOTBR was 5.08 s. FDOTS of subject 25 was 7.68 s, and FDOTBR was 5.66 s.

Figure 3. Fixation durations of the first group.

Data related to fixation time in the first group of experiments were extracted and averaged (all values mentioned below are the average values of 29 samples) for processing and analysis. The results are shown in Figure 4a. The three groups of data were found to have the same trend. Data related to the building distribution form and the experimental fixation time of the first group of experimental samples were extracted to draw the trend chart, as shown in Figure 4b. Buildings in sample 1 are distributed in a decentralized way, and the percentage of FDOTBR to FDOTS accounts for 49.80%. Buildings in sample 2 are distributed in a decentralized and concentrated way, and the percentage of FDOTBR to FDOTS accounted for 60.11%. Buildings in sample 3 are distributed in a concentrated way, and the percentage of FDOTBR to FDOTS accounted for 69.25%. Figure 4b shows that the more dispersed the buildings are, the shorter the fixation duration on buildings will be. In other words, in the environment of buildings, the visual attraction of dispersed building groups is weaker, and the sense of the presence of buildings in the environment is lower.

Sample	Sample 1	Sample 2	Sample 3
FDOTS (s)	7.57	7.52	7.48
FDOTBR (s)	3.77	4.52	5.18
Percentage	49.80%	60.11%	69.25%

(a)



(b)

Figure 4. Analysis of fixation time in the experiment 1: (**a**) Data related to fixation time in the experiment 1 and (**b**) relationship between the percentage of FDOTBR to FDOTS, and the distribution of building blocks (the experiment 1).

Similarly, the site environment area and the building area in the second group of experimental samples were divided into different AOI selections for analysis. The relevant fixation time data of the site and the building were detected and averaged, and the results are shown in Figure 5. For instance, in sample 4, FDOTS and FDOTBR of subject 2 was 7.47 s and 6.45 s. FDOTS and FDOTBR of subject 15 was 6.95 s and 5.92 s. FDOTS and FDOTBR of subject 20 was 7.29 s and 5.98 s. In sample 5, FDOTS and FDOTBR of subject 3 was 7.41 s and 3.95 s. FDOTS and FDOTBR of subject 6 was 7.52 s and 3.72 s. FDOTS and FDOTBR of subject 12 was 6.95 s and 3.38 s.

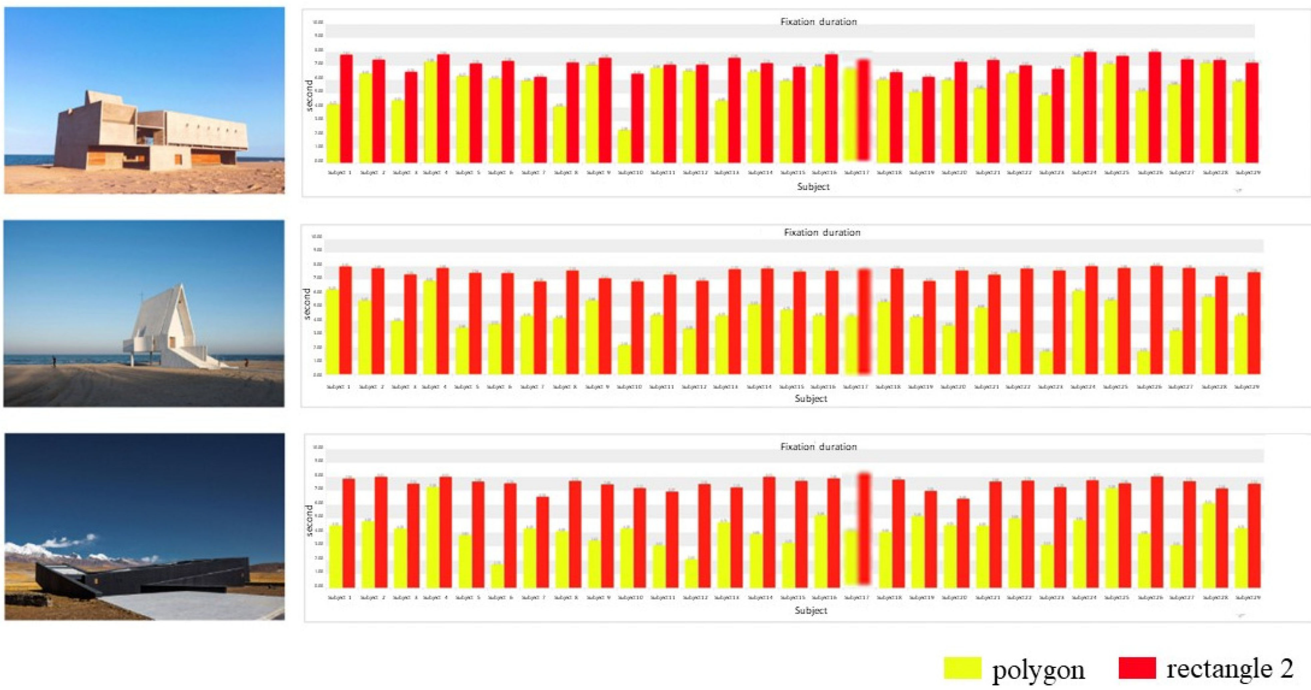


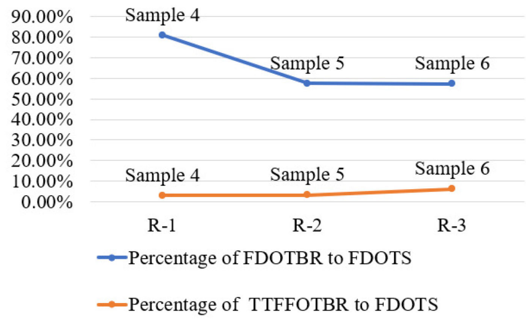
Figure 5. Fixation durations of the experiment 2.

Data related to fixation time in the second group of experiments were extracted for processing and analysis, and the results are shown in Figure 6. For samples 4–6, the percentage of FDOTBR to FDOTS were 80.97%, 57.52%, and 57.24%, respectively, which were positively correlated with the trend of the S/L ratios of buildings. The percentage of time to first fixation on the building region (TTFFOTBR) to FDOTS were 3.03%, 3.30%, and

6.24% (Figure 6a), showing an inverse correlation with the trend of the S/L ratio of building blocks (Figure 6b). According to the analysis, the larger the S/L ratio of the building blocks, the more focus would be needed for subjects on the building. Through the comprehensive comparative analysis of the above two groups of experimental data, the smaller the S/L ratio of building blocks is, the more dispersed the form would be, and the lower its sense of existence.

Sample	Sample 4	Sample 5	Sample 6
FDOTS (s)	7.25	7.58	7.53
FDOTBR (s)	5.87	4.36	4.31
TTFFOTBR (s)	0.22	0.25	0.47
Percentage of FDOTBR to FDOTS	80.97%	57.52%	57.24%
Percentage of TTFFOTBR to FDOTS	3.03%	3.30%	6.24%

(a)



(b)

Figure 6. Analysis of fixation time in the experiment 2: (**a**) Data related to fixation time in the experiment 2; (**b**) relationship between the percentage of fixation time and the S/L ratio (the experiment 2).

4.2. Correlation Analysis of Building and the Environment Based on Fixation Trajectory

The correlation between buildings and the environment refers to the degree to which the building is related to the environment, precisely the degree to which people are concerned about the environment when they see the building. The more backtracks the eye-tracker monitors, the more attention people pay to environment when they see buildings. Through the collection and sorting of backtrack times (times that eyesight shifts back to the last subject) of three samples in the first group of experiments (Figure 7), the average data related to fixation trajectories of the first group of experiments were obtained (as shown in Figure 8a), showing the same trend in the three groups of data given by samples 1 to 3. As shown in Figure 8b, the trend chart was drawn based on the distribution forms of related buildings in the first group of experiments above. The percentages of average regression count on the building region (ARCOTBR) to average saccade on the sample (ASOTS) of samples 1 to 3 were 49.54%, 55.89%, and 63.48%, respectively. Upon analysis, it can be seen that the distribution of building form is more concentrated, and the percentage of ARCOTBR to ASOTS is higher. According to known principles of human brain functioning when processing backward saccades, the more dispersed the distribution of buildings is, the weaker the correlation between buildings and the environment will be.

Similarly, the average data related to the fixation trajectory of Experiment 2 (Figure 9) were obtained by collecting and sorting the backtrack times of three samples in Experiment 2 from the building part (as shown in Figure 10a). The three groups of data in samples 4–6 had the same trend. Considered in the relation to the S/L ratio analysis of related building blocks in the second group of experiments above, the trend chart, as shown in Figure 10b, was drawn up: and it was found that in samples 4–6, the percentages of ARCOTBR to ASOTS were 10.31%, 15.54%, and 15.57%, respectively. According to the analysis, the percentage is inversely correlated with the trend of the S/L ratio of building blocks. In other words, the greater the S/L ratio of building blocks are, the weaker will be the correlation between the building and the environment.

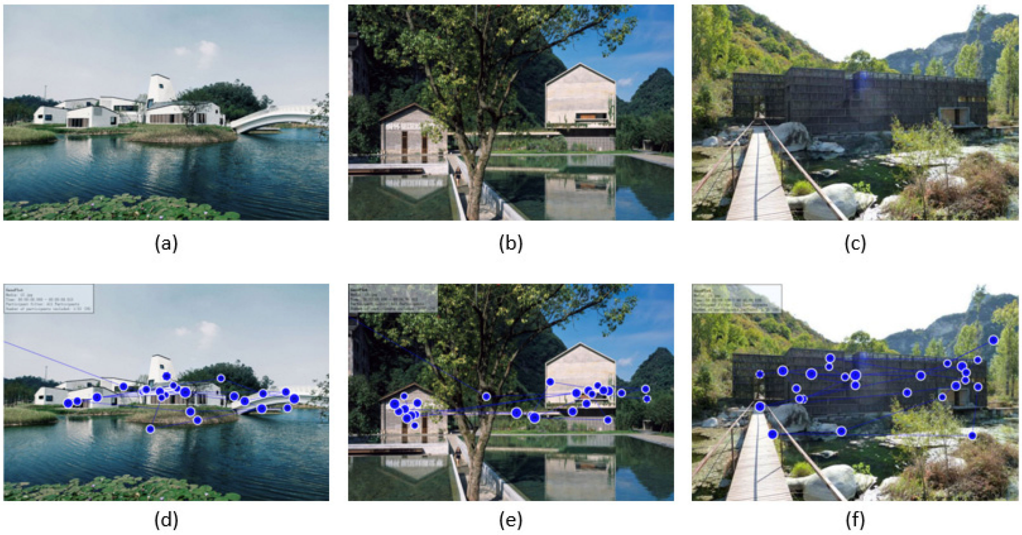
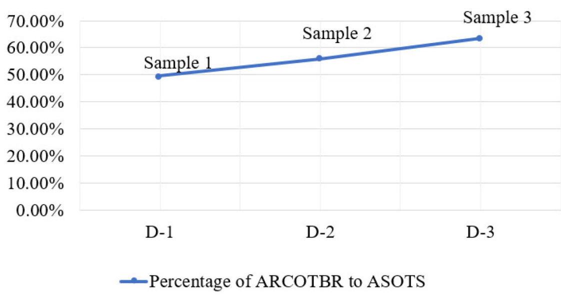


Figure 7. Fixation trajectories of the first group of experiments: (**a**) Sample 1; (**b**) Sample 2; (**c**) Sample 3; (**d**) Sample 1 fixaion track map; (**e**) Sample 2 fixation track map; (**f**) Sample 3 fixation track map.

Sample	Sample 1	Sample 2	Sample 3
ARCOTBR (times)	11.87	15.04	18.30
ASOTS (times)	23.96	26.91	28.83
Percentage	49.54%	55.89%	63.48%

(a)



(b)

Figure 8. Analysis of fixation trajectory in experiment 1: (**a**) Relevant data for fixation trajectory in Experiment 1 and (**b**) relationship between the percentage of ARCOTBR to ASOTS, and the distribution of building blocks (the experiment 1).

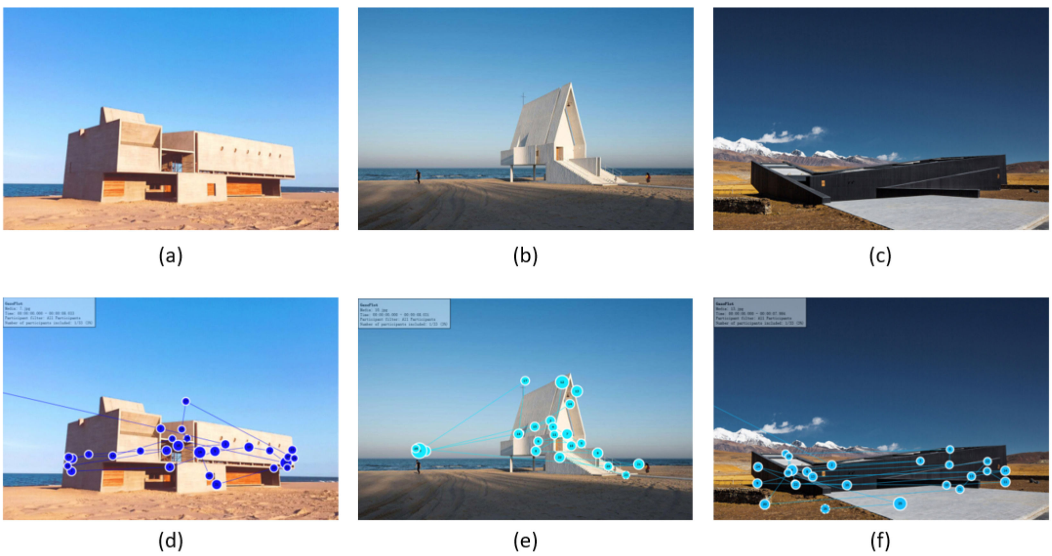
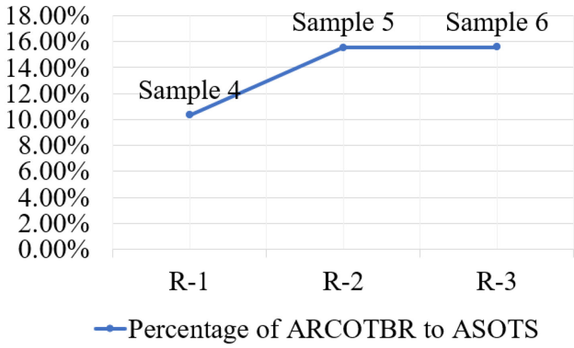


Figure 9. Fixation trajectories of the experiment 2: (**a**) Sample 4; (**b**) Sample 5; (**c**) Sample 6; (**d**) Sample 4 fixation track map; (**e**) Sample 5 fixation track map; (**f**) Sample 6 fixation track map.

Sample	Sample 4	Sample 5	Sample 6
ARCOTBR (times)	3.35	4.55	4.15
ASOTS (times)	32.48	28.96	26.65
Percentage	10.31%	15.54%	15.57%

(a)



(b)

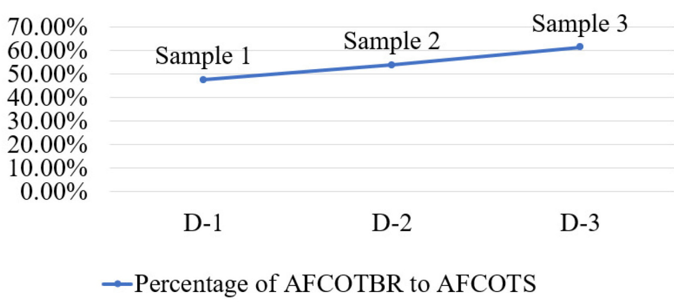
Figure 10. Analysis of fixation trajectory in experiment 2: (**a**) Relevant data for fixation trajectory in Experiment 2 and (**b**) relationship between the percentage of ARCOTBR to ASOTS, and the S/L ratio (the experiment 2).

4.3. Analysis of Building Information Search Quantity Based on the Number of Fixation Points

The site environment and building area in the first group of experimental samples were divided into different AOI selections for analysis. The number of interrelated fixation points of the site and the building was detected. The average value was taken to obtain data related to fixation time in the first group of experiments (as shown in Figure 11a), and the three groups of data had the same trend. The trend chart shown in Figure 11b was drawn based on the distribution forms of related buildings in the first group of experiments: in Skacamples 1–3, the percentage of average fixation counts on the building region (AFCOTBR) to average fixation counts on the sample (AFCOTS) were 47.56%, 53.89%, and 61.35%, respectively. The analysis results have shown a positive correlation between a greater average number of fixations in the building selection and a higher concentration of the building distribution. In other words, the more dispersed the distribution of buildings are, the eye movements tracked indicate that the subjects would make less effort in searching for building information.

Sample	Sample 1	Sample 2	Sample 3
AFCOTBR	11.87	15.04	18.30
AFCOTS	24.96	27.91	29.83
Percentage	47.56%	53.89%	61.35%

(a)



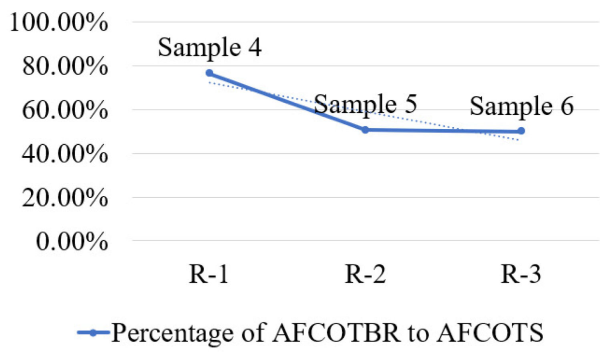
(b)

Figure 11. Analysis of the fixation points in the experiment 1: (**a**) Data related to the number of fixation points in the experiment 1 and (**b**) relationship between the percentage of AFCOTBR to AFCOTS, and distribution of building blocks (the experiment 1).

Similarly, the site environment area and the building area in the second group of experimental samples were divided into different AOI selections for analysis, the number of related fixation points between the site and the building was detected, and the average value was taken in order to obtain the data pertaining to the fixation time in the second group of experiments (as shown in Figure 12a). The three groups of data showed the same trend. The trend chart, as shown in Figure 12b, was drawn based on the analysis of the S/L ratio of buildings in the second group of experiments. Among them, the percentages of AFCOTBR to AFCOTS in the Samples 4–6 were 76.50%, 50.54%, and 49.96%, respectively. Based on the analysis results, the proportion of the average number of fixation points in the sample was positively correlated with the trend of the S/L ratio of building blocks. In other words, the larger the S/L ratio of the building blocks are, the greater would be the tendency for the subjects to search for the building information.

Sample	Sample 4	Sample 5	Sample 6
AFCOTBR	25.61	15.14	13.81
AFCOTS	33.48	29.96	27.65
Percentage	76.50%	50.54%	49.96%

(a)



(b)

Figure 12. Analysis of the fixation points in the experiment 2: (**a**) Data related to the number of fixation points in the experiment 2 and (**b**) relationship between the percentage of AFCOTBR to AFCOTS, and the S/L ratio (the experiment 2).

5. Discussion and Conclusions

With the aid of eye-tracker experiments, this study analyzed how the distribution and the S/L ratio of building blocks affect the eye-movement behaviors, and, in turn, proposes corresponding design strategies for the building blocks.

Analysis of the three sets of experimental data from Samples 1, 2, and 3 revealed that the more dispersed the distribution of the building blocks, the more it would cause increased levels of eye movements, shorter fixation duration, and less fixation points. This means more contact surfaces between building and environment can enhance saccade behaviour. Separated building blocks or an interrupted shape can increase the contact surface between building and environment, so the architect can use such design strategies to increase the saccade behaviour between the building and environment area. Visually, this helps to enhance the integration of the building with the natural environment. Analysis of the three sets of experimental data from Samples 4, 5, and 6 revealed the discovery that the larger the S/L ratio of building blocks, the more it is likely to cause less eye movement, longer fixation duration, and more fixation points. Just imagine what an exaggerated thing it would be to suddenly see a supertall building on a prairie. So, reducing the S/L ratio of the building blocks helps to enhance the integration of the building with the natural environment when designing it.

Furthermore, the frequency of eye movement is a key feedback of the effort made by the viewer for purposes of information searching. So, changing the ratio of S/L and adjusting the distribution of building blocks are both ways of trying to reduce the amount of visual information expressed in the buildings. Therefore, when architects want to change the relationship between buildings and the environment, they can also change the building's color and materials to control the expression of the building's visual information instead of designing the building blocks.

Compared with other articles that examine the relationship between buildings and the environment, this study conducts advanced research on the visual expression of architecture and broadens the scope of earlier approaches to research in this field. For instance, some published articles suggest a more integrated environment with a larger ratio of height-to-width values for individual buildings in urban mid-rise clusters. Some published articles suggest that controlling the height of building masses in waterfront-built environments in cities is beneficial to the overall visual expression. Some published articles suggest that the continuous layout of building blocks in a mountainous environment is more pleasing to the eye. This study analyses the ratio of S/L and the distribution of the building blocks in the natural environment and draws conclusions that are slightly different from the above-mentioned results. This shows that there is no fixed standard for the ratio and distribution of the building blocks. It is significant to analyze these two standards based on the environment in which the building is located.

Architecture is a three-dimensional, environmental, multi-sensory, and temporal domain of human perceptual reality. It brings people's senses of hearing, touch, sight, smell, and other perceptions into play when engaged in architectural conceptualization and design. These factors, combined with the complex effects of multiple other influences, can inspire architects to decide to design a building with various forms of expression. However, it is extremely difficult to meaningfully analyse the experimental variables if we begin by combining all the relevant technical aspects, so, in this paper, we select a single element of vision to study architecture. In the future, the relationship between building and the environment can be analysed from other perceptual perspectives, making the study more comprehensive.

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Abbreviations

AOI	Area of Interest
S/L	The ratio of the shorter side (S) to longer side (L) of building blocks
H	Hue
S	Saturation
B	Brightness
FDOTS	Fixation duration on the sample
FDOTBR	Fixation duration on the building region
FDOTER	Fixation duration on the environment region
TTFFOTBR	Time to first fixation on the building region
ARCOTBR	Average regression count on the building region
ASOTS	Average saccade on the sample
AFCOTBR	Average fixation counts on the building region
AFCOTS	Average fixation counts on the sample

Appendix A

Questionnaire

Dear Madam/Sir,

I am a student of the School of Architecture, Harbin Institute of Technology. Now I am doing research on the visual integration relationship between architecture and natural environment. The information obtained is for academic research only.

Please answer within the brackets. Thank you for your sincere cooperation!

Please answer the following questions according to the above pictures.

1. Please choose the picture that you think is the best effective (   ).
2. Please choose the picture that you think is the least effective (   ).
3. Please select the picture that you think has the best visual integration relationship between architecture and natural environment (   ).
4. Please select the picture that you think has the worst visual integration relationship between architecture and natural environment (   ).

Please answer the following questions according to the pictures you have just looked at.

1. Please choose the picture that impresses you most (   ).
2. Please choose the 6 pictures that impressed you most (   ).

End of the questionnaire.

Thank you for your cooperation!

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