Effect of the degree of wood use on the visual psychological response of wooden indoor spaces

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Abstract: The exhausting fast pace of life in modern urban society is leading to overwhelming stress and diminished cognitive alertness. Moreover, people are spending more and more time indoors due to building densification and urban lifestyle. Therefore, indoor environments that can promote positive psychological perception will become more important. Use of wood in indoor settings and its health benefits are currently receiving increased attention from design and research communities. In this work, a comparative study was conducted on the different degrees of wood use in indoor spaces. The results show that the effect of the physical attributes of degree of wood use, wood coverage and change of wood surface (different type and application position of wood) on the visual psychological responses (visual attention and psychological impression) of wooden indoor spaces were significant. The wooden indoor spaces with medium degree of wood use were easier to get more visual attention and were more helpful to give people the psychological impression of naturalness, warmth, relaxation, and desire to use. In addition, the results also show that when considering the influence of change of wood surface, people tended to pay more attention to indoor spaces with relatively high wood coverage and preferred the experiences in such spaces. The change of wood surface was an all-important aspect that needs to be considered on top of wood coverage. These results provided guidance for the design of healthy indoor environments.

Key words: visual attention, psychological impression, wooden indoor spaces, degree of wood use, eye-tracking

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1 Introduction

Wood is widely used in the building sector due to its advantages in sustainability, carbon sequestration, and eco-friendliness (Gerilla et al., 2007; Head et al., 2020; Jiménez et al., 2016; Li et al., 2020). This is especially true in countries like Canada, Finland, China, Sweden, and USA (Nyrud et al., 2010). Additionally, studies showed that using wood in buildings could create warm and relaxing living environment with distinct visual effects (Burnard et al., 2017; Rice et al., 2007; Sakuragawa, 2006), and wood used in buildings may enhance dialogues between modern technology and traditional–regional practices (O'Connor et al., 2004; Xu et al., 2018). Therefore, wood is critical when it comes to expressing essential characteristics of architectural space and promoting a natural, warm, and healthy indoor living experience.

In recent years, new sustainable building practices have emerged by integrating the psychological, physical, and behavioral needs of occupants (Beatley, 2012; Lau et al., 2014; Mohtashami et al., 2016). Along with the increasing awareness of healthy building design, the relationship between occupants' health and building materials was emphasized (Andreassi, 2010; Burnard and Kutnar, 2020). Using wood in interior spaces and its corresponding benefits to human experience are currently receiving unprecedented attention.

1.1 Visual perception of wood environments

In general, human beings acquire most information of the physical environment through vision. The evaluation of the visual effect for wood has always been the focus of related researches, the visual impression and preference of wood differ because of a number of factors such as species, color, number of knots, and surface treatment (Manuel et al., 2015; Nakamura and Kondo, 2008; Fujisaki et al., 2015; Hib and Nyrud, 2010; Broman, 2001). For example, Nakamura and Kondo (2008) concluded that clear wood leads to more relaxed eye patterns than knotty wood. However, features such as deep red grooves could mask the effects of the knots to some degree. In addition, wood was considered warmer because the perceived hue of wood was generally in the range of yellow and red, which was associated with the perception of warmth (Watchman et al., 2016; Rametsteiner et al., 2007). Masuda (2004) found an even larger positive correlation between settings that were evaluated as warm, and the color of wood, especially with the increasing value of the yellow-red spectrum. Some studies have concluded that visual wood exposure could lead to beneficial outcomes (Bamba and Azuma, 2015; Hib and Nyrud, 2010), but the research evidence is limited in this field—some studies, like the study by Bamba and Azuma (2015), showed that the subjects' faster rate of fatigue perception reduction in room contained cedar paneling, but it was not clear whether the difference was caused by the intensity of the cedar's odor intensity or cedar's visual effect. Lipovac et al. (2020) measured cognitive performance in participants at desks with differing top surfaces and the results indicated that cognitive outcomes did not differ. It appears that a relatively small wood surface does not significantly influence cognitive performance. The human visual preference for wood is the basis for the observed positive human response in wood environments (Burnard and Kutnar, 2015; Lipovac and Burnard, 2020), and wood coverage is an important variable of wood use in wooden visual environments (Nyrud et al., 2014; Zhang et al., 2016); therefore, the effect of different wood coverages on visual preference that need to be explored further.

1.2 Psychological response of wood environments

Balling and Falk (1982) pointed out an innate or evolutionary preference for natural scenes. The stress recovery potential of nature was a remarkable phenomenon; however, it was of little practical day-to-day relevance for the urban majority (Lindal and Hartig, 2013). Kaplan (1987) suggested that such a preference would evolve or be learned if natural scenes afforded an advantage or benefit. Ulrich’s stress reduction theory (Ulrich, 1983) and Kaplan’s attention recovery theory (Kaplan and Kaplan, 1989) explained the importance of the naturalness of building environments. Wood is a natural product, and therefore people have clearly positive attitudes toward wood, and an interior room that contains wood facilitates restoration and provides stress reduction (Fell, 2010; Lipovac and Burnard, 2020).

Burnard and Kutnar (2015) reviewed the literature on the psychological responses toward wood published in the last thirty years. In these studies, it is pointed out that wood is commonly perceived as natural and warm (Rametsteiner et al., 2007). However, people do have different attitudes toward different wood species. For example, oak was seen as masculine, and mahogany was seen as elegant (Blomgren, 1965). In general, the evaluation of solid wood samples was very high (Jonsson et al., 2008). At the same time, people do have different attitudes toward different application positions of wood. For example, people think that the wood materials used for flooring of indoor space were most livable (Sakuragawa, 2006). In addition, people have different attitudes toward different amounts of wood. For example, rooms with wood coverage approaching 50% were seen as the warmest (Masuda and Nakamura, 1990). However, these studies only considered the effects of a single wood application variable (Jafarian et al., 2018; Rice et al., 2007; Tsunetsugu et al., 2007), and the diversity of wood application on space surface cannot be controlled by a single indicator. A previous study included multiple physical variables like wood coverage, material combinations, and wood patterns, but it focused specifically on exterior surface of buildings (Xu et al., 2019). The present study considers multiple variables influencing the visual psychological responses of wooden indoor spaces, and it extends previous researches on preference opportunities seen in a wood space.

1.3 Importance of physical attributes relevant for visual psychological response

Many studies have evaluated the differences of people's preference for wood environment and non-wood environment, and results showed that wood environment had higher acceptance and preference evaluation (Spetic et al., 2007; Rice et al., 2007; Cronhjort et al., 2017). Some studies have considered the cognitive evaluation of psychological benefits provided by wood environment, such as warmth and naturalness (Nyrud and Bringslimark, 2010; Burnard and Kutnar, 2015). There are also some studies that directly explain the specific material characteristics that affect the visual impression of wood environment, such as wood color, wood species, wood coverage, and application position of wood (Rice et al., 2007; Sakuragawa, 2006; Rametsteiner et al., 2007; Masuda, 2004; Nyrud et al., 2010; Tsunetsugu et al., 2005, 2007). These results can provide reference in selecting physical attributes that affect visual perception and psychological impression of indoor wood space. Therefore, in the following, two physical attributes for the degree of wood use in wooden indoor spaces are considered, which are the wood coverage and the change of wood surface.

1.3.1 Wood surface

The wood surface of space can be divided into building surfaces for enclosing interior space (for example, Nyrud et al. (2014) study applied wood to flooring, walls, and ceilings; Tsunetsugu et al. (2002) applied wood to floors, walls, and beams) and furniture surfaces (for example, Fell (2010) study applied wood to chairs, desks, window blinds and shelves; Burnard and Kutnar (2020) applied wood to desks with large shelves), and the present study examined the effects of wood on building surfaces. Sakuragawa's (2006) study examined the preference of wood materials for floors, walls, and wallboards, and the results showed that the photos showing wood materials only used for flooring were evaluated as the subjects' favorite place to live and considered as the most livable space. It appears that wood is the most preferred in flooring in living spaces. At the same time, studies have also shown that wood has the highest evaluation when applied to vertical walls (Nyrud and Bringslimark, 2010). However, the change of wood surface cannot be controlled by a single indicator, and the change of wood surface in these studies is still simple, and cannot satisfy actual applications. Therefore, the effect of multivariate change of wood surface on the visual psychological response needs to be explored further.

1.3.2 Wood coverage

Wood coverage refers to the proportion of the wood surface area in the indoor space surfaces area, excluding the window. Wood coverage is an important variable of wood use in wooden visual environments. Some studies have examined the effect of wood coverage on visual impression and reported that there was an inverted U-shape relationship between the impression for indoor spaces and the increase in wood coverage (Nyrud et al., 2014; Zhang et al., 2016; Cronhjort et al., 2017). Furthermore, some studies have incorporated varying degrees of wood coverage, such as 0%, 45% (or 50%), and 100%. The results showed that environments with large amounts of wood and without wood were considered most novel, and environments with medium amounts of wood were considered to be the warmest and most comfortable (Masuda and Nakamura, 1990; Tsunetsugu et al., 2007).

1.4 Objectives of the study

The present study focuses on exploring the effect of different degrees of wood use on the visual psychological response (visual attention and psychological impression). Two physical attributes of the degree of wood use are wood coverage and change of wood surface (including the different types and application positions of wood). These physical attributes systematically varied in a set of computer-generated spatial images. The investigators initially designed an eye-tracking study to test visual attention. Then, in a subjective scoring program, the psychological impression of wooden indoor spaces in different situations was evaluated to understand the influence of different degrees of wood use on visual psychological response. Instead of just making a simple comparison of the psychological reaction in wood environments and non-wood environments, this present study mainly explores the following hypotheses:

1. At the lower end of the degree of wood use, increasing wood coverage and change of wood surface of wooden indoor spaces can get more visual attention in terms of eye-tracking and get higher score in terms of psychological impression ratings.

2. The change of wood surface has a more significant effect on the visual psychological response, when compared to wood coverage of wooden indoor spaces.

2 Method

Figure 1 shows the research framework, case studies, literature review, eye-tracking study, and subjective scoring methods used in the research process, which are described in the following sections in more detail.

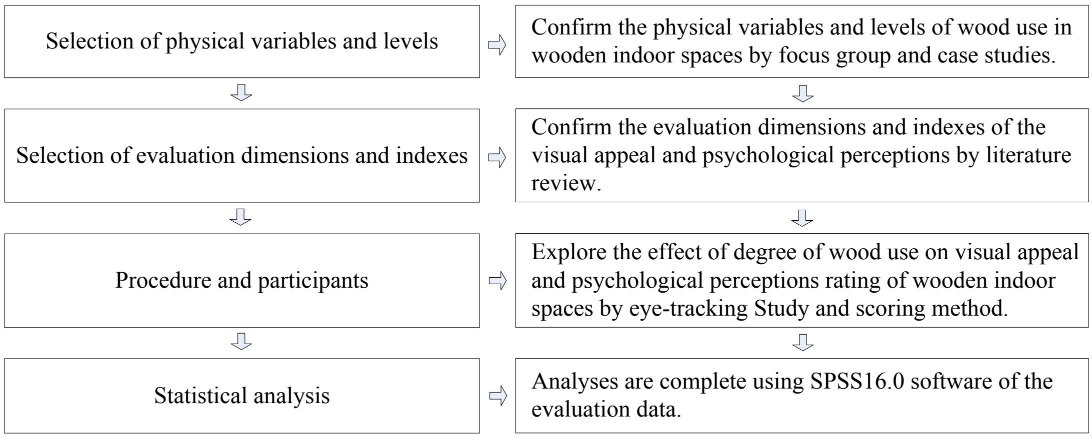


Fig. 1 Research framework

2.1 Selection of physical variables and levels

This paper takes images of wooden indoor spaces as the object of research, which were selected from the most influential awards, magazines, and websites in the field of timber building design, and the details are shown in Table 1. The standard for case selection was that each project had detailed introductory information and images of indoor space. However, only one main wooden indoor space was selected for statistics in each case, and subsequent analysis was conducted in the selected space.

Table 1
Data source of case statistics

The data source		Cases number	Total
Award	Wood Works, Wood Design Award, Australian Timber Design Awards, Mies Crown Hall Americas Prize, NZ Wood Resene Timber Design Awards	134	
Magazines	Detail, Wallpaper	64	477
Websites	Design Wooden Building	103	
Subscribe to the no	Canadawood, Woodstructure, Canadawoodchina、Muwusheji	104	
Field trips	Canada, Britain, Finland, Japan, Austria	72	

First, the main physical variables influencing the visual psychological responses of wooden indoor spaces were developed with the help of a focus group discussion. As the literature showed that it was effective to organize 6 to 12 people in a focus group discussion (Campbell et al., 2014; Rihn et al., 2016), ten graduate students of Harbin Institute of Technology (including one host and one recorder of the meeting, and three men and five women) participated in the discussion. The participants had a strong academic background in timber building design and environment behavior psychology. The host guided the discussion of topics prepared in advance. The results of the discussion revealed that four variables of wood use may affect the visual psychological responses of wooden indoor spaces, which were the wood coverage, wood type, wood color, and the position of wood in the spatial surface. Then, according to the selected 477 wooden indoor spaces, the above four variables of wood use were counted. The statistical results are confirmed in Fig. 2. It shows that the wood coverage was distributed in a certain number of cases within the 5%–95% interval, the timber building tended to promote the application of mass timber, and the six timber products were the dominating types, as shown in Table 2, which were mainly used as beams, roofs, floors, columns, and walls in the building spaces, as shown in Fig. 3. The dominant wood color was warm yellow–orange; therefore, in the present study, wood color was not considered. Based on this, the following physical variables and the levels displayed in the present research are given in Table 3.

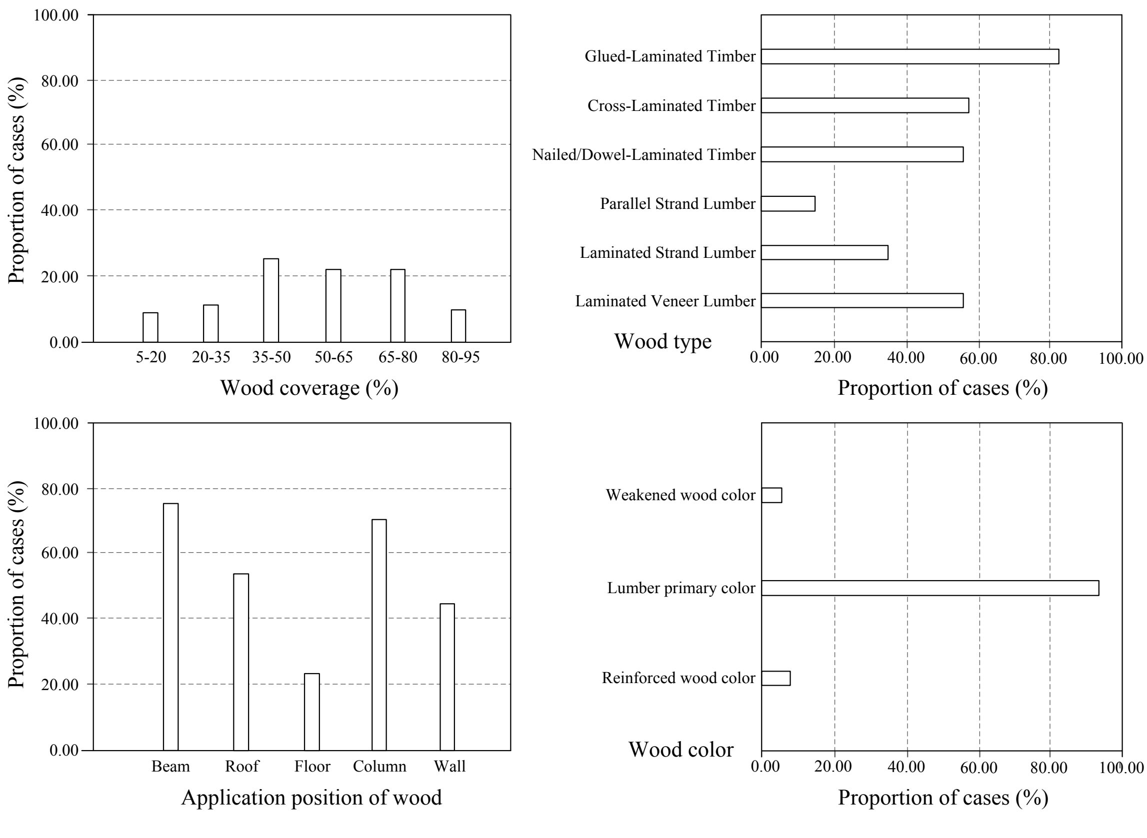


Fig. 2 Statistical results of physical variables of wood use (N=477)

Table 2
Common types of timber products in practical timber construction engineering

 Glued-Laminated Timber (GLT)	 Cross-Laminated Timber (CLT)	 Nailed/Dowel-Laminated Timber (NLT/DLT)
 Parallel Strand Lumber (PSL)	 Laminated Strand Lumber (LSL)	 Laminated Veneer Lumber (LVL)

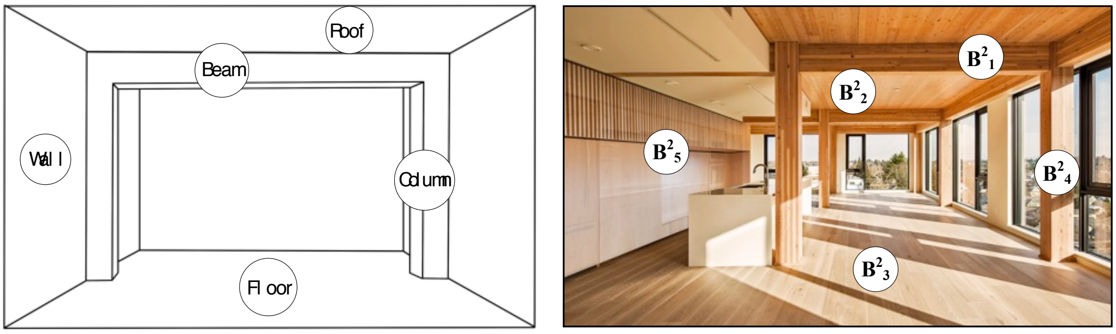


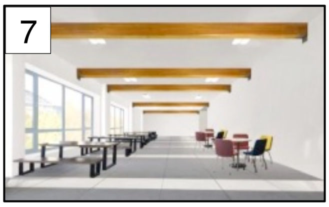
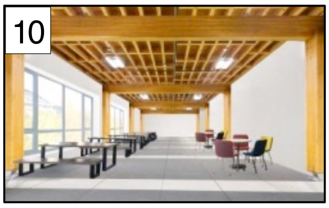
Fig. 3 Enclosure surfaces of indoor space and the application position of wood

Table 3
Principal physical variables and levels of wood use in wooden indoor spaces

Physical variables		
Wood coverages (%) A	Change of wood surface B	
	Type of wood B^1	Application position of wood B^2
1: 5-20	1: GLT	1: Beam
2: 20-35	2: CLT	2: Roof
3: 35-50	3: NLT (DLT)	3: Floor
4: 50-65	4: PSL	4: Column
5: 65-80	5: LSL	5: Wall
6: 80-95	6: LVL	

Over 100 combinations can be obtained from the levels of variables in Table 3. In order to simplify the subsequent tests and prevent aesthetic fatigue, with the help of case statistics, the investigators determined the two dominant types of change of wood surface for each level of wood coverage of the wooden indoor space (e.g., when the wood coverage was 5%–20%, the commonly used wood products were GLT and LSL, and these tended to be used as wood beams and wood walls. Finally, the two material variables) (wood coverage and change of wood surface) were systematically controlled in the 12 images of wooden indoor space, as shown in Table 4.

Table 4
Principal types and common design methods of wood use by case studies

Principal types	Common design methods and images of wooden indoor space	
$A_1 : 2B(1B^1+1B^2)$	 $A_1 : (B^1_1+B^2_1)$	 $A_1 : (B^1_6+B^2_5)$
$A_2 : 3B(1B^1+2B^2)$	 $A_2 : (B^1_1+B^2_1B^2_4)$	 $A_2 : (B^1_6+B^2_2B^2_5)$
$A_3 : 4B(2B^1+2B^2)$	 $A_3 : (B^1_1B^1_5+B^2_1B^2_5)$	 $A_3 : (B^1_1B^1_6+B^2_1B^2_2)$
$A_4 : 5B(2B^1+3B^2)$	 $A_4 : (B^1_1B^1_3+B^2_1B^2_2B^2_4)$	 $A_4 : (B^1_1B^1_5+B^2_1B^2_2B^2_5)$
$A_5 : 6B(2B^1+4B^2)$	 $A_5 : (B^1_1B^1_6+B^2_1B^2_2B^2_4B^2_5)$	 $A_5 : (B^1_1B^1_3+B^2_1B^2_2B^2_4B^2_5)$
$A_6 : 7B(3B^1+4B^2)$	 $A_6 : (B^1_1B^1_2B^1_6+B^2_1B^2_2B^2_3B^2_4)$	 $A_6 : (B^1_1B^1_3B^1_6+B^2_1B^2_2B^2_4B^2_5)$

The "change of wood surface" refers to the change of indoor space surface caused by the difference of wood type (B^1) and application position of wood (B^2). In the wooden indoor spaces, the change of wood surface is one of six levels (from 2 to 7), and the level of change is represented by the sum of the number of wood types and the number of application positions. When only one type of wood product (grade 1) and one position (grade 1) is used in the indoor space, and the change of wood surface is grade 2 (1 + 1), which is the lowest level of wood surface change. When three types of wood products (grade 3) are applied to four surfaces (grade 4) of indoor space at the same time, the change of wood surface is grade 7 (3 + 4), which is the highest level of change in this study (Table 4). In addition, there were six levels of wood coverage. Stamps (2002) pointed out that "entropy" aggregates objective changes that provide a basis for subjective evaluations of visual diversity. Inspired by the assessment of entropy, this study proposed "degree of wood use" to characterize objective changes of wood interior space. Because the "degree of wood use" is defined as the changes of wood coverage, type, and application position in three degrees of low, medium, and high, and it is more convenient for participants to evaluate the objective change of wooden indoor spaces, as shown in Table 5.

Table 5
Physical variables in the analysis

Degree of wood use A+B	Wood coverage (%) A	Change of wood surface B (B^1+B^2)	Principal types of wood applications	Image No.	
Low	5-20	2	A_1 : 2B(1B^1+1B^2)	1	7
	20-35	3	A_2 : 3B(1B^1+2B^2)	2	8
Medium	35-50	4	A_3 : 4B(2B^1+2B^2)	3	9
	50-65	5	A_4 : 5B(2B^1+3B^2)	4	10
High	65-80	6	A_5 : 6B(2B^1+4B^2)	5	11
	80-95	7	A_6 : 7B(3B^1+4B^2)	6	12

2.2 Selection of evaluation dimensions and indexes

Two evaluation methods—an eye-tracking study and a scoring method—were used to explore the effect of degree of wood use on visual attention and psychological impression of wooden indoor spaces. In the analysis, the seven indicators of visual attention and psychological impression were investigated, as given in Table 6.

Among these, fixation duration and number of fixations were the main analysis indexes for the eye-tracking test output. Although using eye-tracking technology to investigate the relationship between consideration of wood use visual stimuli and attention of indoor space was rare, however, the research on people's fixation behavior in behavioral psychology can provide reference for the expected results of this experiment. 83% of the information humans use is gathered visually (Wästlund et al., 2012). The eye-movement measurement in reading research shows that information acquisition is mainly obtained during fixation, and we can examine the participants' attention distribution by the fixation time obtained from different images (Xuejun et al., 2008; Balcombe et al., 2013). The test data shows participants' visual attention, where longer fixation duration and higher number of fixations represent more concentrated attention (Guoli et al., 2013; Sa and Yiang, 2018). When the fixation duration and number of fixations are inconsistent, the most attractive part of the visual environment can be described by the fixation heat map, which can intuitively display the most attractive part of the image.

Based on the literature review, the items naturalness, warmth, relaxation, interest, and desire to use the space were included in the evaluation of psychological impression. Naturalness, warmth, and relaxation were included because Rice et al. (2007) used photos of different living rooms to investigate the effect of various materials on people's preferences; the results revealed that living rooms with wood were more popular than rooms without wood, and these were described as more natural, warmer, and more relaxed. Interest was included because Broman (1995, 1996, 2001) found that to assess people's preference for wood, there are at least ten characteristics of importance, including the evaluation of interest. Desire to use the space was included because Sakuragawa's (2006) research showed that the photos of the interior of a room without wooden materials were evaluated as a place where subjects did not want to live compared with the room with wooden materials. Based on this, the subjects were asked to evaluate the five indicators (Table 6) by subjective scoring. A questionnaire was designed with five items to measure psychological impression using a 7-point scale (0 = not at all; 6 = completely).

Table 6
Evaluation dimensions and indicators of the visual psychological response

Variable	Evaluation dimensions	Evaluation indicators
Visual psychological response	Visual attention	Fixation duration
		Number of fixations
	Psychological impression	Naturalness
		Warmth
		Relaxation
		Interest
		Desire to use

2.3 Procedure and participants

To avoid the interference of the subjective scoring on the eye-tracking study, the experiment was conducted in the following procedure.

The eye-tracking test was conducted at the Environmental Psychology Laboratory at Harbin Institute of Technology. Firstly, according to the research purpose, the multiple space images in Table 4 are presented on one view page (1750 x 1900 pixels), which was called a group page (i.e., group page 6 as shown in Fig. 4, six images of wooden indoor space representing different degrees of wood use were arranged on one group page). There are eight group pages in the test; among these, there are four group pages (group page 1, 2, 5 and 6) with six images, respectively, and four group pages (group page 3, 4, 7 and 8) with three images, respectively, as shown in Table 7. Then, the eight group pages were entered into a computer with an image display. The participants can view each group page on the computer screen for 15 s. This short observation time is defined to prevent the subject from becoming bored and to record sufficient eye-tracking data for analysis (Nakamura and Kondo, 2008). To minimize the visual interference before the next image, a blank page was added between the two group pages, and the display time of the blank page was set to 5 s.

The participants were not told what was the purpose of the study. They were just told that they were free to view the images as they pleased. The study measured the number of fixations and average fixation durations for different images present on the screen as an indicator of awareness (Antonides, 2017; Xu et al., 2019). The procedures for the test as shown in Fig. 5 were as follows: (1) calibrate the Tobii TX300 eye tracker; (2) calibrate the participant's eye position, confirming the participant's eye movements to be accurately monitored; (3) display the group of images on the computer screen in front of the participant for 15 s for each test session; (4) save the eye-tracking data. After the eye-tracking test, a short interview was conducted with each subject on this question (what was your psychological activity when you pay attention to something during the experiment) to gain insight into their most authentic thoughts and motivations of the subjects.

After the eye-tracking test, the participants were asked to imagine that he/she was in the space shown in the image and to rate the space design on five psychological impression variables. The participants' perceptions of the spaces were obtained by asking the following five questions: (1) Does the space make you feel close to nature? (2) Does the space make you feel warm? (3) Does the space make you feel relaxed? (4) Does the space make you feel like there was much to explore and discover? (5) Do you want to use the space? To avoid aesthetic fatigue during the evaluation process, and reflect the three degrees of wood use (low, medium, and high), participants were only required to rate group page 3, group page 4, group page 7 and group page 8, evaluating one group page at a time.

Table 7
Eight group pages in the test

Degree of wood use	Group page 1		Group page 2		Group page 3	Group page 4
Low	1	7	2	8	1	2
Medium	3	9	4	10	3	4
High	5	11	6	12	5	6
Degree of wood use	Group page 5		Group page 6		Group page 7	Group page 8
Low	1	2	7	8	7	8
Medium	3	4	9	10	9	10
High	5	6	11	12	11	12

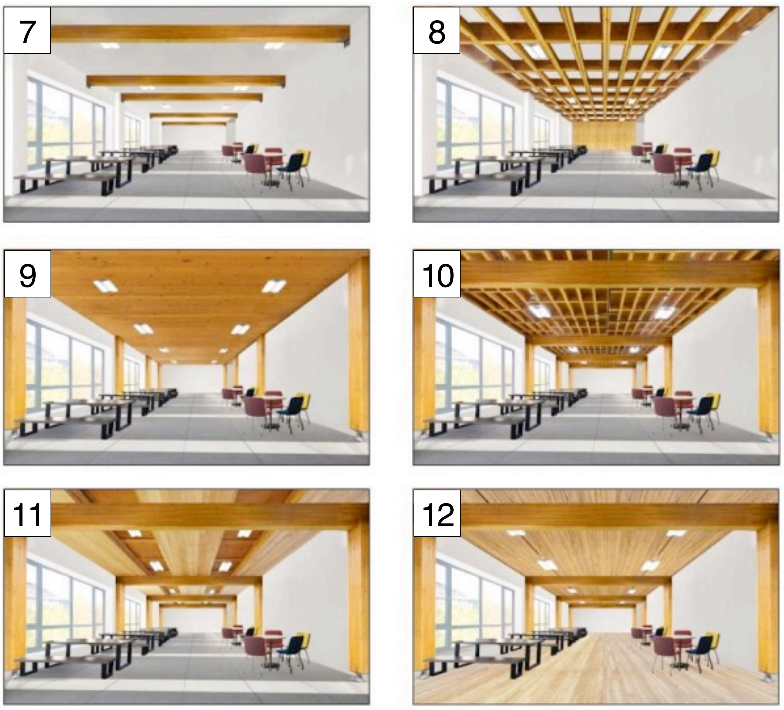


Fig. 4 Group page 6

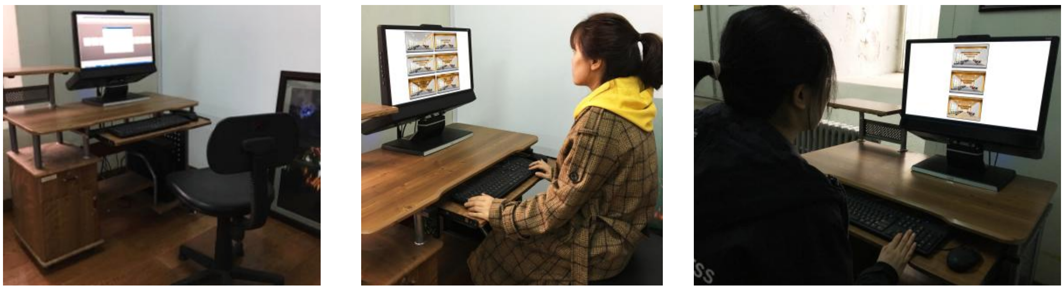


Fig. 5 Scene photos of the eye-tracking test

The participants (n=75) were comprised of 27 male and 48 female university students. Among these participants, 30 (10 males and 20 females) participated in the eye-tracking experiments, open-ended interviews, and subjective scoring, and the other 45 only took part in the subjective scoring. The participants were aged 23-30 years, all of these participants had an architectural background, and 17 of these participants were familiar with modern wooden architecture. A student population was chosen for this study for several reasons. Firstly, students were a readily available population for campus studies. Secondly, the test subjects of most of the previous research on the perceptions of wooden indoor spaces were college students (Burnard and Kutnar, 2015; Jafarian et al., 2018; Masuda and Yamamoto, 1988), choosing a student population would enable the results to be comparable with the findings of other studies. Finally, a student population also was a relatively homogeneous sample in terms of demographics (Fell, 2010; Peterson, 2001), which eliminated some of the noise that a more diverse sample would impart.

2.4 Statistical analysis

In the present study, the images of wooden indoor space were the units of analysis, and the physical variables used in the analysis reflected the degree of wood use. The values for physical variables were the results obtained from researcher manipulations, while the visual psychological response was measured using the participant ratings. Each image was rated on each of the seven indicators of visual psychological response. Among these, the evaluation of visual indicators was completed by eye-tracking study, and the psychological indicators were assessed by subjective item rating. The raw data for the present study included wood coverage, change of wood surface, fixation duration, number of fixations, score, and demographic data. The demographic data consisted of age in years, gender, and specialty category. The mean of the ratings for each image was used for further analysis.

These analyses were completed using the SPSS software (Lindal and Hartig, 2013; Xu et al., 2019). The statistical techniques employed for analysis were descriptive statistics, paired sample t test, and correlation analysis. p values less than 0.05 indicated a statistically significant difference. The correlation analysis to look for the effect of the physical attributes (wood coverage and change of wood surface) on the visual psychological response of wooden indoor spaces was compared and analyzed, in order to determine the relationship between these two. Paired sample t test was performed to identify the differences between mean values, when the degree of wood use changed from low to medium, medium to high, and low to high. According to the three groups of wood application degree comparison (medium-low, high-medium, and high-low), the fixation duration, number of fixations, and subjective evaluation data of the eye-tracking experiment were compared, which comprised nine groups. In addition, the fixation duration and fixation times of three kinds of spatial surfaces were compared and analyzed.

3 Results and discussion

3.1 Effect of wood use on visual attention

The eye-tracking test data analysis results indicated that the wood coverage and change of wood surface were positively correlated with the fixation duration and number of fixations in space ($p<0.05$), as shown in Table 8. This shows that the wood coverage and change of wood surface in indoor spaces have a significant impact on the visual attention of the spaces. Change of wood surface had a greater correlation with fixation duration and number of fixations than wood coverage. Thus, the change of wood surface was an important aspect that needs to be considered on top of wood coverage.

Table 8
Correlation matrix for the variables under study by eye-tracking test

Variables	1	2	3	4
Wood coverage (%)	1.00			
Change of wood surface	0.85^{**}	1.00		
Fixation duration	0.19^{*}	0.31^{**}	1.00	
Number of fixations	0.27^{**}	0.28^{**}	0.11	1.00

*significant level $p<0.05$; **significant level $p<0.01$

The images representing different degrees of wood use were placed in the same view. For the viewing time of 15 s, the number and duration of fixations are shown in Fig. 6. The results indicated that fixation duration (T=6.57 s) was the longest, and the number of fixations (N=20.60) was the highest under a medium degree of wood use. In addition, by paired sample t test, the differences in fixation duration and number of fixations of wood space images with different degrees of wood use were tested, and the results are shown in Table 9. The fixation duration and the number of fixations were significantly higher for space images with medium degree of wood use compared to those with low degree, at the level of $p<0.05$. Furthermore, the fixation duration and the number of fixations were relatively higher for space images with medium degree of wood use than those with high degree, just the difference was not significant. It can be seen that fixation duration and number of fixations increased with the increase in degree of wood use, with a peak when the degree was medium and then decreased with further increase in degree of wood use (Fig. 6).

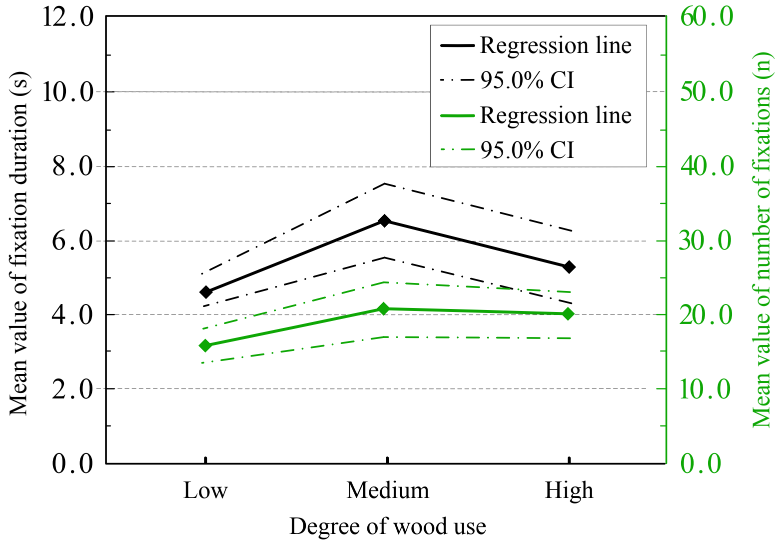


Fig. 6 Fixation duration and number of fixations of different degrees of wood use

Table 9
Increased visual attention of wooden indoor spaces with the degree of wood use

Visual indicators	Paired samples	Degree of wood use	Pairwise difference M	Pairwise difference SD	t	Sig.(2-tailed)
Fixation duration	1	Medium-Low	1.93	2.44	4.32	0.00**
	2	High-Medium	-1.26	3.42	-2.02	0.05
	3	High-Low	0.67	2.93	1.25	0.22
Number of fixations	1	Medium-Low	4.83	11.59	2.28	0.03*
	2	High-Medium	-0.57	13.00	-0.24	0.81
	3	High-Low	4.27	9.63	2.43	0.02*

*significant level $p<0.05$; **significant level $p<0.01$

In the open-ended interview after the eye movement experiment, all participants stated that they would pay more visual attention to images of wooden indoor space which they were more interested. Although some participants indicated that the furniture and window view would also receive some attention, their visual focus was still on the wood surface. To further prove that the wood surface was the main visual appeal of the wood space, the enclosing surface of the space was divided into three parts: wood surface, non-wood surface, and window surface. In the present study, the tables and chairs were included in the category of non-wood surface. The Tobii TX300 eye tracker can separately output the fixation duration and number of fixations for the selected target area in the image, in order to define the more visually attractive region in the spatial image, as shown in Fig. 7. At the same time, paired sample t test was used to analyze the difference in fixation duration and number of fixations between the wood surface and non-wood surface. The results are shown in Table 10. The fixation duration and number of fixations on the wood surface were significantly higher than that on the non-wood surface and window surface ($p<0.01$). This shows that without any goals and tasks, the wood surface can receive more attention in the 15 s of free viewing time.

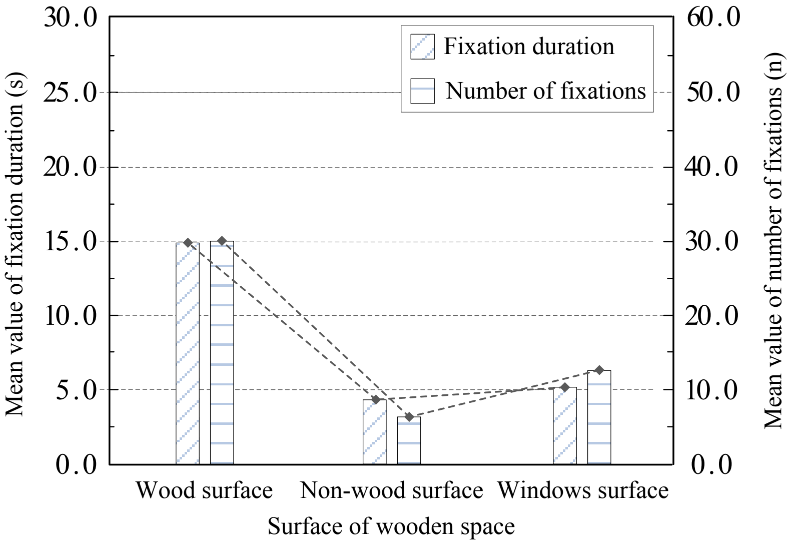


Fig. 7 Visual attention allocation of wooden spaces

Table 10
Paired sample t test for eye-tracking data

Visual physical	Paired samples	Space surfaces	Pairwise difference		t	Sig.(2-tailed)
			M	SD		
Fixation duration	1	Wood-Non-wood	10.84	9.28	3.50	0.01**
	2	Wood-Windows	11.67	8.34	4.20	0.00**
Number of fixations	1	Wood-Non-wood	17.67	15.31	3.46	0.01**
	2	Wood-Windows	24.00	11.12	6.47	0.00**

*significant level p<0.05; **significant level p<0.01

3.2 Effect of wood use on psychological impression

Table 11 shows the correlation matrix between the variables in the impression evaluation, indicating that there was a significantly positive correlation between these five indicators, and all significantly and positively correlated with the change of wood surface. However, only three indicators were significantly and positively correlated with the wood coverage (p<0.05), which can reason that the change of wood surface has a greater influence on psychological impression of wooden indoor spaces than wood coverage. Furthermore, the rated mean values of the various evaluation indicators (except interest) of psychological impression were generally high, and these fell within a narrow range. This shows that wooden indoor spaces generally have a high rating. On average, the wooden indoor spaces elicited moderate-to-high ratings of naturalness, warmth, relaxation and desire to use, and low-to-moderate ratings of interest.

Table 11
Descriptive statistics and correlation matrix for the variables

Variables	M	SD	1	2	3	4	5	6
Wood coverage (%) [a]	-	-	1.00					
Change of wood surface [a]	-	-	0.83**	1.00				
Naturalness [b]	3.52	0.59	0.14**	0.23**	1.00			
Warmth [b]	3.53	0.48	0.13**	0.19**	0.73**	1.00		
Relaxation [b]	3.57	0.47	0.03	0.11*	0.69**	0.76**	1.00	
Interest [b]	2.47	0.53	0.24**	0.16**	0.09*	0.06	-0.05	1.00
Desire to use [b]	3.52	0.49	-0.01	0.09*	0.64**	0.66**	0.74**	-0.09*

Values in the correlation matrix are for Pearson correlations. *significant level p<0.05; **significant level p<0.01
[a] Higher values indicate higher levels, [b] Ratings given on a 7-point scale (0=not at all, 6=completely)

Figure 8 shows the mean values of various evaluation indicators for different degrees of wood use. It can be seen that among each evaluation indicator, the participants have the highest ratings for “naturalness," "warmth," "relaxation," and "desire to use" of wooden indoor spaces with medium degree of wood use (S_n=4.08, S_w=4.05, S_r=4.14, S_d=4.15). This shows that the wooden indoor spaces with medium degree of wood use were more helpful to give people the psychological impression of naturalness, warmth, relaxation, and desire to use. The images of wooden indoor spaces with the lowest evaluation, closest to the average, and highest psychological impression are shown in Fig. 9. Specifically, the impression evaluation score of wood space with GLT beam-column and NLT/ DLT or CLT roof is higher. This is because although the six types of wood considered in this study are all engineering wood (i.e., mass timber), the processing degree of GLT, CLT, and NLT/DLT is relatively lower compared with that of PSL, LSL and LVL. Therefore, this kind of space is relatively easy to awaken the participants' perception of nature and get a higher score.

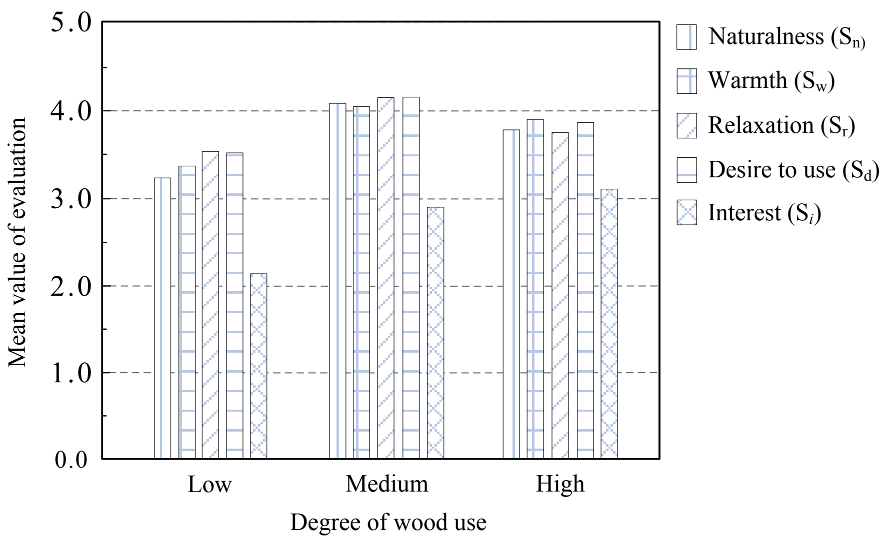


Fig. 8 Mean values of various evaluation indicators for different degrees of wood use

A_1+$B^1{}_6$+$B^2{}_5$ A_3+$B^1{}_1B^1{}_6$+$B^2{}_1B^2{}_2$ A_4+$B^1{}_1B^1{}_3$+$B^2{}_1B^2{}_2B^2{}_4$

Fig. 9 Wooden indoor space images with the lowest, near-average, and highest evaluation mean

The psychological impressions of wooden indoor spaces with different degrees of wood use (low, medium, and high) were measured by the mean score of all evaluation indicators. The results of the paired sample t test showed that the evaluation mean of wooden indoor spaces with medium, high degree of wood use was significantly higher than that of low wood use degree, and the mean value of wooden indoor spaces with medium degree of wood use was higher than that with high wood use degree, just the difference was not significant enough, as shown in Table 12. It can be seen that the degree of wood use with the psychological impression of wooden spaces had an inverse V-shaped relationship, as shown in Fig. 10. In other words, people tend to give more positive evaluations to the wooden indoor spaces with medium degree of wood use, at least when the degree of wood use was below the moderate level. Increasing the wood coverage and change of wood surface in indoor spaces can help improve people's good psychological perception. Specifically, the psychological impression of wooden spaces was at the best level when the wood coverage is in the range of 35—65% and the change of wood interface is 4 level or 5 level.

Table 12
Paired sample t test by subjective ratings

Paired samples	Degree of wood use	Pairwise difference 95% confidence intervals				t	Sig.(2-tailed)
		M	SD	Upper	Lower		
1	Medium-Low	0.70	0.48	0.38	1.06	4.76	0.00**
2	High-Medium	-0.23	0.36	-0.51	0.01	-2.18	0.06
3	High-Low	0.47	0.40	0.19	0.76	3.74	0.01**

*significant level $p<0.05$; **significant level $p<0.01$

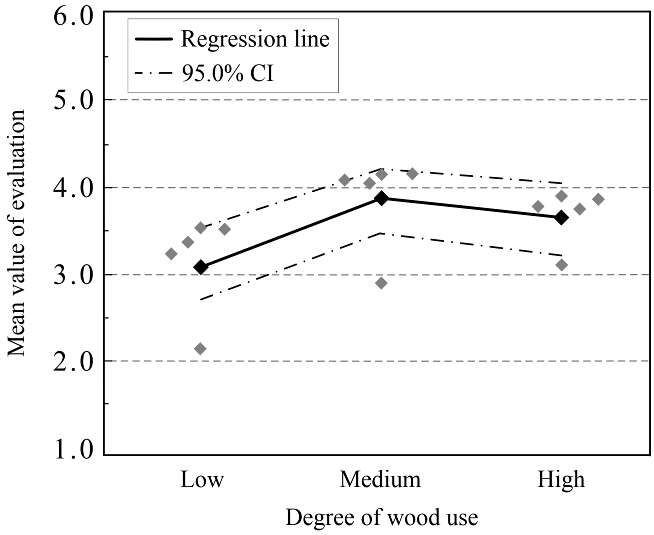


Fig. 10 Variation trend of psychological impression to scoring with the degree of wood use

These results show that the wooden indoor spaces with medium degree of wood use were easier to get more visual attention and were more helpful to give people the psychological impression of naturalness, warmth, relaxation, and desire to use. This is because although wood is a natural product, most of the wood use in buildings is yellow and orange, which makes wooden indoor spaces easy to bring warmth to people, while large area of wood coverage would make the space appear narrow and create a sense of restraint. Therefore, when the degree of wood use in the space reaches the highest level, the subject's evaluation on the perceived naturalness, relaxation, and desire to use wooden indoor spaces would decrease. It is noteworthy that previous studies have revealed that the most pleasing amount of wood coverage for indoor spaces was approximately 45% or 50% (Masuda and Nakamura, 1990; Tsunetsugu et al., 2007), and that the present study revealed that the psychological impression was optimal when the amount of wood coverage was within 50-65%. Since simply covering a large area of wood on the surface of indoor space would make the space appear narrow and create a sense of restraint, changing the wood surface would appropriately weaken the feeling of enclosure of the space and in turn result in psychological relaxation and intimacy. Therefore, people can also accept the relatively large area of wood coverage in the indoor space. Moreover, it can be imagined that when more variables (such as wood color, wood surface texture, and wood component form) are added in the follow-up study, wooden indoor spaces with a high wood utilization rate would receive a higher evaluation.

In summary, regardless of whether it is from the consideration of creating high-quality wood indoor spaces, or for saving wood, the degree of wood use is an important limiting index. Specifically, although wood is more subjectively preferred to other construction materials in building environments, it does not mean that more wood is better. Controlling the degree of wood use at the medium level can achieve higher preference, and controlling the degree of wood use at the low level can optimize the quality of indoor spaces while saving wood, which is especially important for countries where wood is scarce like China. At the same time, the study extended previous research on preference seen in a wood space, through the systematic manipulation of physical attributes in timber buildings and through the assessment of visual attention by eye-tracking test.

Theoretically, the fast pace of life and work stress has reduced people's access to nature and forced people to spend more time indoors (Burnard and Kutnar, 2020). The present results confirm that wood surface in the indoor spaces has more visual appeal and allows for more visual unconscious exploration. The attention recovery theory points out that people can alleviate attention fatigue by entering attractive and interesting environments. Therefore, it can be noted that wooden indoor spaces provide a restorative environment for the fast-paced urban life. This is one of the main reasons why timber has received increasing attention in healthy buildings, and that the wood use can also play a significant role in the development of green buildings. Such information is needed to create building environments that are sustainable in social and psychological terms as well as in ecological terms. This conclusion can provide guidance to identify physical attributes that affect the restorative experience in wood indoor environments.

More studies should be conducted outside the laboratory in the field. The two-dimensional color images used in this work have some limitations. For example, it may be difficult to judge the preference of a space without a broader environment. Although Stamps reported a strong correlation (r=0.86) between environmental evaluations obtained on-site and those obtained through photographs (Stamps, 1990, 2010), it can still be acknowledged that such stimuli do constrain the environmental experience somehow, for example, the perception of sounds and light in real architectural space. In addition, more work needs to be done for different design, structures, building functions (such as hospitals, schools, workplaces, and nursing home), or people of different ages and different health conditions.

4 Conclusion

The present study examined the human visual psychological responses through 12 computer-generated images of wooden indoor spaces with three degrees of wood use (low, medium, and high). The visual attention was measured using fixation duration and the number of fixations as indicators, and the psychological impression was evaluated using “naturalness," "warmth," "relaxation," “interest,” and "desire to use" as an indicator. The results show that at the lower end of the degree of wood use, increasing wood coverage and the change of wood surface positively affected visual attention and psychological perception, which peaked when the degree of wood use was medium and then decreased with further increase in the degree of wood use, i.e., the degree of wood use with the visual psychological response of wooden spaces had an inverse V-shaped relationship. The results of the eye-tracking test indicated that the correlation between change of wood surface and visual indicators was greater than that between wood coverage and visual indicators. The results of the subjective rating show that the change of wood surface was significantly correlated with all five evaluation indicators of psychological impression, while wood coverage was significantly correlated with three of these. This indicates that the change of wood surface was an all-important aspect that needs to be considered on top of wood coverage.

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