

Article

Evaluation Method and the Influence of Visual Comfort of Ceramic Tiles in Indoor Environment—A Study Based on the Delphi and AHP

Jiayin Chen ^{1,*}, Yue Cheng ²  and Qingyun Guo ²¹ School of Art and Design, Zhejiang Sci-Tech University, Hangzhou 310000, China² School of Design and Art, Jingdezhen Ceramic Institute, Jingdezhen 333000, China; 2110012001@stu.jcu.edu.cn (Y.C.); 2010012002@stu.jcu.edu.cn (Q.G.)

* Correspondence: zheligongchenjiayin@zstu.edu.cn

Abstract: People spend most of their time indoors, and the visual characteristics of indoor building materials affect not only the quality of the indoor environment, but also the well-being of individuals. Ceramic tiles are widely used in interior decoration of buildings due to their aesthetic appeal and ease of maintenance. However, there is currently a lack of a comprehensive framework for assessing the visual comfort of ceramic tile design. This study established an evaluation system using the Analytic Hierarchy Process (AHP) and the Delphi method to collect perceptual words, extract evaluation indices, and calculate weights. A visual comfort scale for ceramic tiles, comprising three dimensions and twelve indices, was developed. A total of 342 questionnaires were analyzed using six types of tiles, and the multidimensional visual comfort scores of the various ceramic tile samples were statistically examined. An analysis of variance was conducted to investigate the effects of tile brightness, texture, and participant gender on visual comfort. The findings indicate that tile brightness and texture significantly affect the overall visual comfort score ($p < 0.001$; $p < 0.001$), with light-toned, non-textured tiles providing higher visual comfort (3.949). Although gender did not significantly affect the overall visual comfort scores, it did influence the evaluation scores in certain dimensions. Men rated the aesthetic comfort of tiles lower than women ($p = 0.035$), but they rated the emotional comfort of medium-toned and non-textured tiles higher ($p = 0.003$; $p = 0.017$). In terms of theoretical significance, the establishment of this evaluation model can expand the research content and methods of ceramic tiles, which are crucial architectural decoration materials. In terms of practical significance, this study provides an evaluation method and partial evaluation information for designers, enabling them to assess and enhance the visual experience of tiles based on the specific needs of interior spaces and the characteristics of the visual subject.

Keywords: ceramic tiles; visual comfort; Indoor environment; Delphi; Analytic Hierarchy Process (AHP); evaluation method



Citation: Chen, J.; Cheng, Y.; Guo, Q. Evaluation Method and the Influence of Visual Comfort of Ceramic Tiles in Indoor Environment—A Study Based on the Delphi and AHP. *Buildings* **2024**, *14*, 2829. <https://doi.org/10.3390/buildings14092829>

Academic Editors: Valerio Roberto Maria Lo Verso and Jiying Liu

Received: 10 July 2024

Revised: 4 September 2024

Accepted: 6 September 2024

Published: 8 September 2024



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1. Introduction

In modern society, individuals spend 90% of their time indoors [1]. Indoor environmental quality (IEQ) has been an important research topic in indoor environments [2]. It encompasses the study of thermal, acoustic, visual, and air quality aspects of indoor environments [3]. Visual comfort in the indoor environment is an important factor influencing occupant productivity [4]. As a result, interior visual elements should not be overlooked in architectural designs. The choice of flooring material can impact the quality of indoor environment and potentially the mood and health of occupants [5]. Ceramic tiles, a fundamental industrial product, are crucial interior building materials [6]. Known for their aesthetic appeal and ease of maintenance, ceramic tiles are commonly used in the interior decoration of buildings. Statistical data show that ceramic tiles are used in over 70% of indoor flooring in buildings, underscoring their widespread adoption [7]. In indoor

environments, the majority of information processed by the brain is visual [8]. People primarily perceive the characteristics of ceramic tiles through visual and tactile senses, with vision being the most important sensory pathway [9]. However, despite being a significant architectural decoration material, current research on the visual perception of ceramic tiles is still incomplete.

Several studies have indicated that formal characteristics influence individuals' preferences for ceramic tiles [10]. For instance, through a questionnaire survey, Agost and Vergara found that ceramic tiles with different formal characteristics evoke associations with attributes such as cleanliness, brightness, and luxury. These associations and emotions significantly impact individuals' preferences for ceramic tiles [11]. Similarly, Mahmood and Tayib discovered through a questionnaire survey that aesthetically pleasing ceramic tiles in interior designs can enhance users' psychological comfort [12]. Serra et al. found that lighter or monochromatic wall and floor colors significantly increase individuals' subjective satisfaction with their environment [13]. Previous studies have explored the relationship between aesthetic preferences for ceramic tiles and neural responses [14,15]. Some researchers have examined the visual pleasantness [11], arousal levels [16], and sense of spatial scale [17] associated with indoor ceramic tiles. For instance, in his doctoral dissertation, Wang Chong used virtual reality technology and questionnaire surveys to find that ceramic tiles, compared to other interior decoration materials such as wallpaper, provide a greater sense of spatial scale [17]. However, evaluating visual comfort for ceramic tiles involves a wide range of factors, including color-induced temperature perception, spatial perceptions of openness or confinement, aesthetic comfort, and emotional responses such as calmness or tension. Currently, there is no comprehensive framework for assessing the visual comfort of ceramic tile designs, and certain evaluation aspects have not been thoroughly addressed. Therefore, developing a model to evaluate the visual comfort provided by indoor ceramic tiles is necessary. In terms of theoretical significance, establishing this evaluation model can expand the research scope and methods for ceramic tiles. In terms of practical significance, this evaluation model can serve as a valuable tool for designers and researchers to assess the effects and experiences of design.

In environmental psychology, the evaluation of indoor environmental perceptions is a well-explored subject [18,19]. Assessing the visual comfort of ceramic tiles involves evaluating the perceived quality of environmental physical characteristics. Research on the visual comfort provided by indoor physical features is both highly significant and valuable. The visual comfort of a ceramic tile design refers to the level of comfort that individuals experience based on their visual perception of ceramic tiles. It provides insights into the evaluation scores of ceramic tiles across various dimensions of visual comfort and reveals how different forms and characteristics influence subjective visual comfort ratings. This understanding will enable designers and researchers to gain a comprehensive understanding of the visual perception of indoor ceramic tile designs, offering evaluation methods and guidance for creating comfortable living and working environments.

The assessment of visual comfort is closely connected to users' emotional experiences with a design. In the study of emotional experiences, Kansei engineering techniques have been widely applied and recognized [20,21]. Kansei engineering is a consumer-oriented product development theory and methodology that aims to integrate human emotions and subjective user experiences into the design and development products and systems. This theory was first proposed by Japanese scholars in the 1980s and has since been widely applied in product design, marketing, and user experience research [22]. At its core, Kansei engineering focuses on the concept of "Kansei," which encompasses human emotions, sensations, and subjective experiences. "Kansei" reflects an individual's emotional response and aesthetic perception of a design. Current designs and marketing strategies often rely on consumers' desires and preferences [23,24]. Therefore, Kansei engineering advocates for designing products based on people's feelings and needs. This theory posits that emotions play a crucial role in shaping user preferences, satisfaction, and overall user experience.

By understanding users and incorporating their desired emotions into the design process, designers can create products that resonate deeply with them on an emotional level.

Utilizing Kansei engineering techniques, this research collected terms commonly used by the public to evaluate the visual comfort of ceramic tiles from literature, websites, and interviews and extracted evaluation criteria from these terms. After gathering the Kansei vocabulary, the Analytic Hierarchy Process (AHP) [25] was used to develop an evaluation index system and calculate the weights of each criterion. Subsequently, the semantic differential (SD) method [26] was employed to establish bipolar scales for these indices. Researchers typically use a five-point or seven-point Likert scale [27] to rate indicators and determine their levels. To support the evaluation process, researchers need to create Kansei experimental materials, including collections of different design features such as color, shape, and texture. After extracting the design characteristics and components, researchers can design the experimental materials. These materials can then be presented to participants along with relevant questionnaires to collect evaluation results.

The purpose of this study was to establish a method for evaluating the visual comfort of ceramic tiles and to understand people's assessments of ceramic tiles by collecting and analyzing participants' evaluation data. First, the researchers developed a multidimensional approach for evaluating the visual comfort of ceramic tiles using the Delphi method and the AHP. Second, to compare the evaluation differences among tiles with varying visual characteristics, participants' evaluations of different tiles were analyzed to determine which tiles offered higher visual comfort and how factors such as brightness, texture, and gender influence the visual comfort evaluations. To achieve this goal, this study addresses the following three research problems:

- (1) How can a multidimensional method for evaluating the visual comfort of ceramic tiles be developed using the Delphi method and the Analytic Hierarchy Process?
- (2) Are there significant differences in people's perceptions of visual comfort for different ceramic tiles?
- (3) How do brightness, texture, and participant gender, as the most important visual factors of ceramic tiles and individual characteristics, affect their visual comfort evaluation scores?

These issues are addressed in the following sections.

2. Materials and Methods

2.1. Materials

The experimental materials used in this study were created using 3D software (Kujiale, China). Given the wide variety of design features of ceramic tiles, the need for a reasonable number of survey questions, and the generalizability of the results, two commonly noted design variables—brightness and texture—were selected as independent variables to assess the visual comfort of ceramic tile design. This choice is supported by Artacho et al., who found that texture and brightness significantly affect the visual perception of ceramic tiles [9]. Agost and Vergara discovered that light-toned tiles are associated with pleasant feelings [11]. The authors' previous research established a relationship between tile brightness and aesthetic preference, indicating that people have the highest aesthetic preference for light-toned tiles, a second-highest preference for medium-toned tiles, and the lowest preference for dark-toned tiles [15]. Therefore, in this study, the brightness factor of the ceramic tiles was divided into three levels: light-toned, medium-toned, and dark-toned. The texture variable was divided into two levels: textured and non-textured. To achieve a two-factor multilevel experimental design, six images of ceramic tiles were rendered, representing the three levels of brightness and two levels of texture (3×2). As this experiment primarily focused on the visual comfort of ceramic tiles, other environmental elements in the experimental materials, such as lighting, furniture, and windows, were kept constant, as illustrated in Figure 1.



Figure 1. Experimental materials for evaluating the visual comfort of ceramic tile design. (a) light-toned $\times$ textured tiles, (b) medium-toned $\times$ textured tiles, (c) dark-toned $\times$ textured tiles, (d) light-toned $\times$ non-textured tiles, (e) medium-toned $\times$ non-textured tiles, (f) dark-toned $\times$ non-textured tiles) for evaluating the visual comfort of ceramic tile design.

2.2. Methods

An evaluation index system for the visual comfort of ceramic tile design can be developed using the Delphi method [28], AHP [29], and the semantic differential method. In this study, the Delphi method was employed, involving 16 experts to summarize the evaluation dimensions and generate the evaluation indicators. Once the questionnaire was created, the semantic differential method was used to evaluate the questions with a 5-point Likert scale. Participants were then recruited to conduct a questionnaire evaluating the tile samples. This study was approved by the Ethics Committee of Jingdezhen Third People's Hospital, China (LL2023007) and was conducted in accordance with the Declaration of Helsinki. All participants provided informed consent. The process was as follows.

2.2.1. Extract Emotional Semantic Words

The evaluation terms related to the visual comfort of ceramic tiles were primarily obtained from four sources: literature databases, online websites, books, and purchase evaluations from ceramic tile users on shopping websites. The literature databases included Web of Science, Google Scholar, and CNKI. Online websites comprised those of more several prominent ceramic enterprises, such as Jinyi Ceramic, Dongpeng ceramic, and Oushenuo Ceramic. Books included various monographs related to ceramic tiles. Finally, purchase reviews on shopping websites such as Taobao and Amazon were also considered. From the collected evaluation terms, similar words were refined, resulting in 27 perceptual evaluation terms. Based on previous research [30], bipolar adjectives related to these Kansei evaluation terms were refined during the initial collection of evaluation criteria to capture the semantic range of the Kansei terms, as shown in Table 1.

Table 1. Bipolar adjective pairs of words for evaluating the visual comfort of ceramic tiles.

Perceptual Evaluation Words of Visual Comfort of Ceramic Tiles	Bipolar Adjective Word Pairs
Sense of brightness	Dim—bright
Sense of vitality	Tired—active
Sense of harmony	Abrupt—harmonious
Sense of capaciousness	Crowded—loose
Sense of fitness	Improper—appropriate
Sense of temperature	Cold—warm
Sense of spaciousness	Closed—open
Sense of softness	Harsh—soft
Sense of openness	Cramped—open
Sense of aesthetics	Ugly—beautiful
Sense of refinement	Coarse—refined
Sense of order	Messy—orderly
Sense of creativity	Ordinary—creative
Sense of fashion	Rustic—fashionable
Sense of elegance	Vulgar—elegant
Sense of simplicity	Redundant—concise
Sense of neatness	Dirty—clean
Sense of uniqueness	Mediocre—unique
Sense of pleasure	Depressed—happy
Sense of calm	Irritable—calm
Sense of charm	Boring—charming
Sense of happiness	Depressed—happy
Sense of warmth	Cold—cozy
Sense of relaxation	Tense—relaxed
Sense of excitement	Apathetic—excited
Sense of intimacy	Aloof—intimate
Sense of peace	Restless—peaceful

2.2.2. Inductive Evaluation Dimension

The Delphi method [28] was employed, and 16 experts were invited to categorize and summarize the emotional vocabulary used to evaluate the visual comfort of ceramic tiles. This study included both academic and practical experts. Academic experts, who made up 50% of the group, consisted of professors, associate professors, and doctoral students engaged in design research at higher education institutions specializing in design disciplines. Practical experts, also accounting for 50%, had over three years of experience in interior design and the ceramic tile industry. Among the experts, 12 (75%) were between the ages of 30 and 50 years, with work experience ranging from 3 to 22 years, averaging 11.8 years. Additionally, 43.75% of the experts held doctoral degrees, and 37.5% had senior professional titles, as detailed in Table 2.

Table 2. Structure of experts' degrees and professional titles.

Professional Title	Number of People	Proportion (%)	Degree	Number of People	Proportion (%)
Professor	3	18.75	Doctor	7	43.75
Associate professor	3	18.75	Master	5	31.25
Lecturer	12	62.5	Bachelor	4	25
Total	16	100		16	100

After two rounds of expert consultation, three main dimensions of the questionnaire on the visual comfort of ceramic tiles were identified (Figure 2). The meanings of these three dimensions are listed in Table 3.

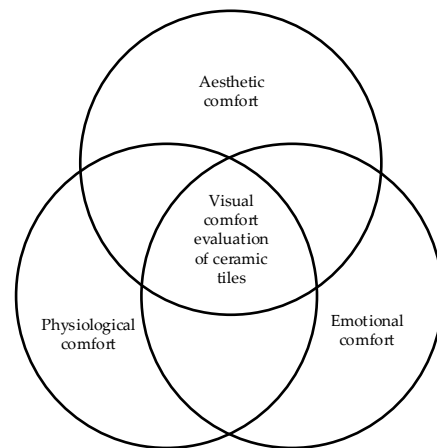


Figure 2. The three key dimensions for visual comfort evaluation.

Table 3. Criteria layer (primary indicators) for evaluating the visual comfort of ceramic tiles and their meanings.

Criteria Layer (Primary Indicators)	Meaning
Physiological comfort	Ceramic tiles make people feel comfortable at the physiological level of visual perception
Aesthetic comfort	Ceramic tiles make people feel comfortable at the aesthetic level of visual perception
Emotional comfort	Ceramic tiles make people feel comfortable at the emotional level of visual perception

(1) Physiological comfort dimension of ceramic tile visual comfort

Physiological comfort resulting from the visual characteristics of an indoor environment is a crucial aspect of environmental comfort [31]. In this study, the physiological comfort dimension refers to the level of comfort experienced at a physiological level when people visually interact with ceramic tiles. Different ceramic tiles can elicit varying physiological comfort experiences. For instance, tiles that are excessively bright or cause significant glare may lead to eye strain and discomfort. Physiological comfort is a fundamental requirement, as when external elements cause physiological discomfort, aesthetic and emotional experiences become challenging to achieve. Therefore, physiological comfort is a critical dimension for evaluating the visual comfort of ceramic tiles.

(2) Aesthetic comfort dimension of ceramic tile visual comfort

Ceramics, as visual and physical elements within a building, interact with the environment, and contribute to aesthetic pleasure through their external qualities, such as color and texture [32]. The aesthetic comfort dimension refers to the level of comfort experienced when people visually engage with ceramic tiles. Various visual forms of ceramic tiles can influence aesthetic perception. For instance, overly chaotic patterns may create visual confusion, while outdated designs may evoke aesthetic displeasure. Thus, the aesthetic comfort dimension is essential when evaluating the visual comfort of ceramic tiles.

(3) Emotional comfort dimension of ceramic tile visual comfort

The emotional comfort dimension pertains to the level of comfort experienced at an emotional level when people perceive ceramic tiles visually. The visual characteristics of ceramic tiles can influence emotional states. For instance, warm and inviting design elements may evoke pleasure [11]. Previous research on perceptions of ceramic tile visual characteristics has enhanced the understanding of emotional comfort related to ceramic tiles [33]. Laparra et al. found that certain types of ceramic tile flooring elicited stronger

emotional responses in users [16]. Ceramic tiles should aim to alleviate stress and foster positive emotional experiences such as joy and relaxation. Therefore, including the emotional comfort dimension in visual comfort evaluation systems is essential.

2.2.3. Determination of Evaluation Indicators

After establishing the primary indicators, secondary indicators were determined through a second round of expert consultations. To ensure the validity of the indicators and ease of response for participants, experts eliminated redundant Kansei evaluation terms. Ultimately, four representative secondary indicators were identified for each of the three primary indicator categories.

Based on the evaluation indices for the physiological comfort dimension from previous similar studies [11,31,34] and expert evaluations in this study, the indicators for the physiological comfort dimension (B1) of the ceramic tile visual comfort (A) were the sense of temperature (C1), sense of brightness (C2), sense of space (C3), and sense of vitality (C4). According to the evaluation indices for aesthetic in previous research [11,35] and expert evaluations of this study, the indicators for the aesthetic comfort dimension (B2) were the sense of order (C5), sense of beauty (C6), sense of refinement (C7), and sense of cleanliness (C8). The emotional quality of ceramic tiles can contribute to emotional comfort [32]. Combining emotional evaluation indicators from previous research [11,16,31,36] with expert evaluations from this study, the indicators for the emotional comfort dimension (B3) were the sense of pleasure (C9), sense of intimacy (C10), sense of calm (C11), and sense of relaxation (C12).

Based on these indicators, an evaluation system for the visual comfort of ceramic tiles was established (Figure 3). The goal layer of the evaluation is represented as A, indicating the visual comfort of ceramic tiles. The criteria layer (primary indicators) includes the three dimensions of evaluation, represented as B1–B3. The indicator layer (secondary indicators) consists of 12 specific indicators across the three dimensions, represented as C1 to C12. The bipolar adjective pairs corresponding to these 12 indicators are depicted in Figure 3.

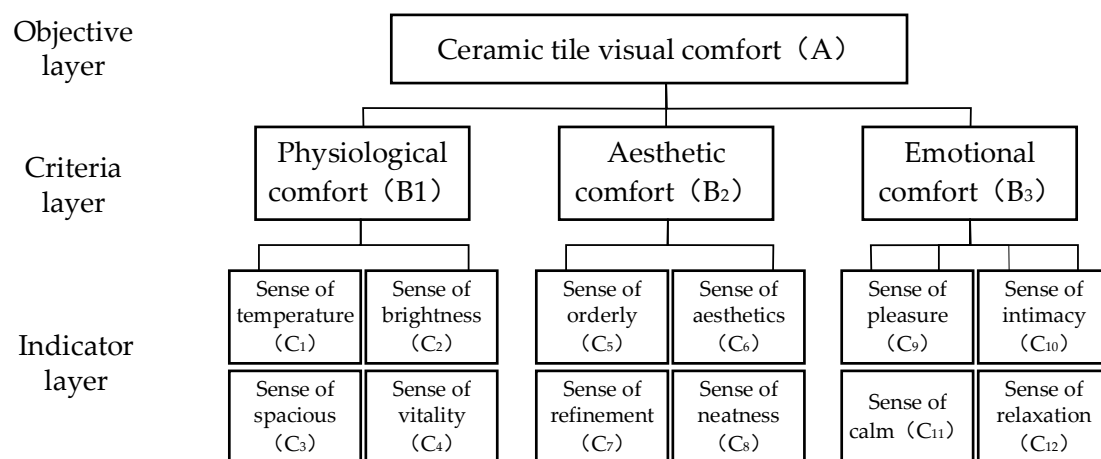


Figure 3. Evaluation system for the visual comfort of ceramic tiles.

2.2.4. Evaluation Questionnaire

After determining the 12 indicators of the indicator layer using semantic differential method [37], this study utilized 5-point Likert scales to evaluate these indicators. Relevant questions were formulated for each of the 12 indicators. The ratings on the scale were interpreted as follows: a rating closer to the positive end of the scale indicated a higher score, while a rating closer to the negative end of the scale indicated a lower score. Consequently, the relevant questions and their corresponding scoring ranges for the survey were established, as detailed in Table 4.

Table 4. Questionnaire for the visual comfort evaluation of ceramic tiles.

Questionnaire
1. Does the ceramic tile feel uncomfortable or moderate in temperature? (1) Very uncomfortable; (2) relatively uncomfortable; (3) neutral; (4) relatively suitable; (5) very suitable.
2. Does the ceramic tile feel harsh/dim or moderate? (1) Very harsh/dim; (2) relatively harsh/dim; (3) neutral; (4) relatively moderate; (5) very moderate.
3. Do the ceramic tiles make people feel cramped or spacious? (1) Very cramped; (2) relatively cramped; (3) neutral; (4) relatively spacious; (5) very spacious.
4. Do the ceramic tiles make people feel sleepy or active? (1) Very sleepy; (2) relatively sleepy; (3) neutral; (4) relatively active; (5) very active.
5. Do the ceramic tiles feel messy or orderly? (1) Very messy; (2) relatively messy; (3) neutral; (4) relatively orderly; (5) very orderly.
6. Do the ceramic tiles here feel ugly or beautiful? (1) Very ugly; (2) relatively ugly; (3) neutral; (4) relatively beautiful; (5) very beautiful.
7. Do the ceramic tiles here feel rough or delicate? (1) Very rough; (2) relatively rough; (3) neutral; (4) relatively delicate; (5) very delicate.
8. Do the ceramic tiles feel messy or neat? (1) Very messy; (2) relatively messy; (3) neutral; (4) relatively neat; (5) very neat.
9. Do the ceramic tiles make people sad or happy? (1) Very sad; (2) relatively sad; (3) neutral; (4) relatively pleasant; (5) very pleasant.
10. Do the ceramic tiles make people feel distant or close? (1) Very distant; (2) relatively distant; (3) neutral; (4) relatively close; (5) very close.
11. Do the ceramic tiles make people feel irritable or calm? (1) Very irritable; (2) relatively irritable; (3) neutral; (4) relatively calm; (5) very calm.
12. Do the ceramic tiles make people feel nervous or relaxed? (1) Very nervous; (2) relatively nervous; (3) neutral; (4) relatively relaxed; (5) very relaxed.

The reliability and validity of the questionnaires were tested using data from 82 pre-test questionnaires and analyzed with SPSS 19.0 (Statistical Package for the Social Sciences, Chicago, IL, USA). SPSS is statistical analysis software used for data processing, analysis, and visualization, providing a range of tools that allow researchers to extract information from data, make decisions, and discover patterns. Reliability, validity, and factor analysis of questionnaire data was conducted using SPSS 19.0. The results indicated an overall reliability of 0.717 for the scale, with individual reliability scores of 0.712, 0.752, and 0.713 for the physiological, aesthetic, and emotional comfort dimensions, respectively. All reliability scores exceeded 0.7, indicating acceptable reliability [38,39].

For validity testing, the Kaiser Meyer Olkin (KMO) measure [40] and Bartlett's test [41] were utilized. The KMO coefficient was 0.71, and Bartlett's test of sphericity had a significance level of less than 0.001. According to scale development methods [42], these results suggest that the questionnaire has good structural validity.

2.2.5. Evaluation Index Weight Calculation

A pairwise comparison of the factors in the criteria layer was conducted through expert evaluation to construct a judgment matrix.

The judgment matrix was constructed using w_i ($i = 1, 2, \dots, m$ and $\sum_{i=1}^m \omega_i = 1$) to represent the weights of the m criteria relative to the goal A. w_i represents the weight coefficient of criterion i relative to the goal A, and B_{ij} indicates the importance ratio between criteria B_i and B_j . Saaty's 1–9 scale method [43,44] was used to determine the importance ratio between the two criteria, ensuring the accuracy of the judgment matrix. Therefore, this study employed the 1–9 scale method to evaluate the weights of the various factors.

Table 5 shows the judgment matrix of criterion layers B1 to B3 relative to objective layer A, which was formed after synthesizing the expert opinions. Tables 6–8 show the

judgment matrices of the indicator layers (C1 to C12) relative to criterion layers B1 to B3 formed after synthesizing expert opinions.

Table 5. The judgment matrix of criteria levels B1–B3 with respect to objective level A.

A	B1	B2	B3
B1	1	2	2
B2	1/2	1	1
B3	1/2	1	1

Table 6. The judgment matrix of indicators C1–C4 with respect to criteria level B1.

B1	C1	C2	C3	C4
C1	1	1/3	1/3	1/2
C2	3	1	2	2
C3	3	1/2	1	3
C4	2	1/2	1/3	1

Table 7. The judgment matrix of indicators C5–C8 with respect to criteria level B2.

B2	C5	C6	C7	C8
C5	1	1/4	1/2	1/4
C6	4	1	3	1
C7	2	1/3	1	1/3
C8	4	1	3	1

Table 8. The judgment matrix of indicators C9–C12 with respect to criteria level B3.

B3	C9	C10	C11	C12
C9	1	3	1	1/2
C10	1/3	1	1/2	1/4
C11	1	3	1	1/2
C12	2	4	2	1

Subsequently, the weight vector and eigenvector of the judgment matrix were calculated, followed by a consistency check. The detailed procedure is as follows:

First, the weight vector for the criteria layer in Table 4 was determined using the root method. The geometric mean of the elements in each row of matrix A was computed using Formula (1):

$$x = \sqrt[m]{\prod_{j=1}^n a_{ij}} \quad (1)$$

The eigenvector of the judgment matrix was denoted by $\omega = (\omega_1, \omega_2, \dots, \omega_m)^T$. It was then normalized using Formula (2) to obtain the weight vector.

$$\omega_i = \omega_i^- / \sum_{i=1}^m \omega_i^- \quad (2)$$

After the weight vector was derived, a consistency check was performed. The maximum eigenvalue, λ_{max} , was calculated using Formula (3).

$$\lambda_{max} = \frac{1}{m} \sum_{i=1}^m \frac{(A\omega)_i}{\omega_i} \quad (3)$$

Subsequently, the consistency index (CI) was determined using Formula (4):

$$CI = (\lambda_{max} - m) / (m - 1) \quad (4)$$

The consistency check must consider the order of the judgment matrix. Saaty suggests using the ratio of the consistency index to the mean random consistency index (RI) to obtain CR for the consistency check [45,46]. The formula is given in Formula (5):

$$CR = CI/RI \quad (5)$$

Based on previous research [24], the values for the random consistency index (RI) are shown in Table 9.

Table 9. Values of consistency indicator RI .

Order of Matrix n	1	2	3	4
RI	0	0	0.58	0.89

When $CR < 0.1$, the matrix was considered to have passed the consistency check. Otherwise, the importance levels within the matrix were adjusted until $CR < 0.1$ was achieved. The procedure was used to calculate the weight coefficients of the indicator layer, resulting in the weight values for each factor in the indicator layer and weight vectors for each matrix. After performing consistency checks on all judgment matrices, all were found to be consistent. The results of the consistency checks are presented in Table 10.

Table 10. Consistency test results.

Judgment Matrix	Normalized Eigenvectors	λ_{max}	CI	RI	CR
A-B1~5	(0.4, 0.3, 0.3)	3.1111	0.0556	0.58	0.0958
B1-C1~4	(0.1064, 0.4079, 0.3192, 0.1665)	4.141	0.047	0.89	0.0528
B2-C5~8	(0.0871, 0.3854, 0.1422, 0.3854)	4.0213	0.0071	0.89	0.008
B3-C9~12	(0.2372, 0.0968, 0.2372, 0.4287)	4.1306	0.0435	0.89	0.0489

After performing the comprehensive calculations, the weight coefficients for each indicator were determined and are presented in Table 11.

Table 11. Weight coefficients for each indicator.

Criterion Layer		Index Level		Comprehensive Weight Coefficient
B1	Physiological comfort	C1	Sense of temperature	0.0426
		C2	Sense of brightness	0.1632
		C3	Sense of spaciousness	0.1276
		C4	Sense of vitality	0.0666
B2	Aesthetic comfort	C5	Sense of order	0.0261
		C6	Sense of aesthetics	0.1156
		C7	Sense of refinement	0.0427
		C8	Sense of neatness	0.1156
B3	Emotional comfort	C9	Sense of pleasure	0.0712
		C10	Sense of intimacy	0.029
		C11	Sense of calm	0.0712
		C12	Sense of relaxation	0.1286
Total				1

After the comprehensive calculations, the ranking of the weight coefficients for each visual comfort evaluation indicator, from highest to lowest, was as follows: brightness, relaxation, spaciousness, aesthetics, neatness, pleasure, calm, vitality, refinement, temperature, intimacy, and order. The results of the weight coefficient calculations aligned well with the perceptions of most experts.

2.2.6. Formula for Total Score Calculation of Visual Comfort of Tiles

During the evaluation process, the scores provided by the participants for each indicator were multiplied by the respective weight coefficients listed in Table 11. The total visual comfort score was obtained by summing the weighted scores. The detailed process is as follows:

Ream $X = (x_1, x_2, x_3, \dots, x_{12})$ for the total vector of the visual comfort evaluation of ceramic tiles, where $S_1, S_2, S_3, \dots, S_{12}$ correspond to people's scores on the 12 indicators, respectively. According to Formula (6), the comprehensive total score S of each participant's visual comfort for ceramic tiles can be obtained.

$$S = s_1 \times x_1 + s_2 \times x_2 + s_3 \times x_3 + \dots + s_{12} \times x_{12} \quad (6)$$

In this evaluation method, the total score of each participant was summed and divided by the number of participants to obtain the average visual comfort score for the ceramic tile. This approach quantifies the visual comfort of ceramic tiles, aiding designers evaluating ceramic tiles across various dimensions.

2.2.7. Questionnaire Collection

As shown in Table 4, researchers completed paper questionnaires and sent them to the participants. After receiving the questionnaire, each participant rated the scenes involving different ceramic tiles (Figure 4). A total of 387 questionnaires were distributed, and 342 valid questionnaires were retained after incomplete and invalid questionnaires were excluded. The ratio of male to female participants was 1:1, and the average age was 20.2 years old. All the participants were young college students with a wide range of professional majors, rather than a single major.



Figure 4. A participant completing a questionnaire.

3. Results

This analysis served two primary purposes. First, it aimed to understand the visual comfort evaluation of the commonly used ceramic tile samples in this study. Second, it sought to assess how factors such as ceramic tile brightness, texture, and participant gender influence visual comfort evaluations. Therefore, the following two sections present the results of the ceramic tile evaluations and discuss the impact of three factors (brightness, texture, and participant gender) on the evaluation outcomes.

3.1. Visual Comfort Evaluation Scores of Different Ceramic Tiles

The score for each ceramic tile sample was calculated from the 342 completed questionnaires using Formula (6). These scores were then averaged by dividing them by the

number of participants. The resulting average evaluation scores for each ceramic tile are presented in Table 12.

Table 12. Average visual comfort evaluation scores of different ceramic tiles.

Sample	Total Value	Physiological Comfort	Aesthetic Comfort	Emotional Comfort
1	3.751	1.585	1.105	1.061
2	3.087	1.235	0.902	0.950
3	2.657	0.989	0.811	0.857
4	3.949	1.588	1.247	1.114
5	3.396	1.298	1.092	1.006
6	2.895	0.994	1.021	0.880

From the average scores of each ceramic tile sample, it is evident that sample (d) (light-toned/non-textured ceramic tile) achieved the highest total score in the visual comfort evaluation, with an average score of 3.949. It also received the highest scores in all three dimensions: physiological comfort (mean = 1.588), aesthetic comfort (mean = 1.247), and emotional comfort (mean = 1.114). In contrast, sample (c) had the lowest total score, averaging 2.657, and recorded the lowest scores in physiological comfort (mean = 0.989), aesthetic comfort (mean = 0.811), and emotional comfort (mean = 0.857).

3.2. Influence of Tone, Texture and Participant Gender in Evaluation of Visual Comfort of Tiles

Before performing the analysis of variance (ANOVA), normal distribution and variance homogeneity tests were conducted on all questionnaire data. The Kolmogorov–Smirnov normality test results for the three dimensions—physiological comfort, aesthetic comfort, and emotional comfort—and the total score data were 0.199, 0.142, 0.221, and 0.177. All these values were greater than 0.05, indicating that the data met the normal distribution requirement. Consequently, ANOVA was conducted. The ANOVA results provided insights into the effects of the ceramic tile factors and participants' gender on the scores for each dimension of visual comfort and the total score. In this analysis, gender was considered as an inter-subject factor, while texture and brightness were treated as intra-subject factors.

3.2.1. Evaluation Results of Physiological Comfort Dimension

The brightness factor of the ceramic tiles [$F(2, 680) = 435.603, p < 0.001$, partial $\eta^2 = 0.562$] had a significant main effect on the physiological comfort dimension score. Light-toned ceramic tiles (mean = 1.586) scored higher than medium- (mean = 1.267) and dark-toned ceramic tiles (mean = 0.991). The texture factor [$F(1, 340) = 3.348, p = 0.068$, partial $\eta^2 = 0.01$] and the gender factor [$F(1, 340) = 0.604, p = 0.437$, partial $\eta^2 = 0.002$] had no significant effect on the physiological comfort score. Participants rated non-textured ceramic tiles slightly higher (mean = 1.293) than textured ceramic tiles (mean = 1.27), and men rated their visual comfort slightly lower (mean = 1.275) than women (mean = 1.288). There were no significant interactions among brightness, texture, and gender [$F(2, 680) = 0.593, p = 0.54$, partial $\eta^2 = 0.002$]. Detailed results are shown in Table 13, which include the main effects and interaction effects. The mean values and standard deviations for the different factors are shown in Tables 14–16.

Table 13. Main and interaction effects of each factor in ANOVA results for the physiological comfort dimension.

Analysis Content	Independent Variable	F	<i>p</i>	Partial η^2
Main effect	Brightness	435.603	<0.001	0.562
	Texture	3.348	0.068	0.01
	Gender	0.604	0.437	0.002
Interaction effect	Brightness * Texture * Gender	0.593	0.54	0.002
	Brightness * Texture	1.894	0.155	0.006
	Brightness * Gender	0.808	0.439	0.002
	Texture * Gender	1.131	0.288	0.003

Table 14. Means and standard deviations of the brightness factor in the main-effect analysis.

Dependent Variable	Light-Toned Tiles		Medium-Toned Tiles		Dark-Toned Tiles	
	Mean	SD	Mean	SD	Mean	SD
Evaluation score of physiological comfort	1.586	0.013	1.267	0.013	0.991	0.017

Table 15. Means and standard deviations of the texture factor in the main-effect analysis.

Dependent Variable	Textured Tiles		Non-Textured Tiles	
	Mean	SD	Mean	SD
Evaluation score of physiological comfort	1.27	0.011	1.293	0.01

Table 16. Means and standard deviations of the gender factor in the main-effect analysis.

Dependent Variable	Male		Female	
	Mean	SD	Mean	SD
Evaluation score of physiological comfort	1.275	0.012	1.288	0.012

3.2.2. Evaluation Results of Aesthetic Comfort Dimension

The brightness factor of ceramic tiles [$F(2, 680) = 196.857, p < 0.001, \eta^2 = 0.367$], the texture factor [$F(1, 340) = 311.637, p < 0.001, \eta^2 = 0.478$], and the gender factor of participants [$F(1, 340) = 4.504, p = 0.035, \eta^2 = 0.013$] all had significant main effects on the aesthetic comfort dimension scores. Specifically, the aesthetic comfort scores for the light-toned ceramic tiles (mean = 1.164) were higher than those for medium-toned (mean = 0.997) and dark-toned ceramic tiles (mean = 0.916). The scores for textured ceramic tiles (mean = 0.931) were lower than those for non-textured tiles (mean = 1.12). Male participants rated the aesthetic comfort of ceramic tiles lower (mean = 1.006) than female participants (mean = 1.045). The interaction effects among brightness, texture, and gender were insignificant [$F(2, 680) = 0.373, p = 0.684, \eta^2 = 0.001$]. However, a significant interaction effect was noted between brightness and gender [$F(2, 680) = 11.564, p < 0.001, \eta^2 = 0.033$]. The main and interaction effects are detailed in Table 17. The means and standard deviations for the different factors are presented in Tables 18–20. Further results of the simple effect analysis indicated a significant difference in the aesthetic comfort ratings for medium-toned ceramic tiles between males and females ($p < 0.001$), with males rating them lower (mean = 0.863) than females (mean = 0.969).

Table 17. Main and interaction effects of each factor in ANOVA results for the aesthetic comfort dimension.

Analysis Content	Independent Variable	F	p	Partial η^2
Main effects	Brightness	196.857	<0.001	0.367
	Texture	311.637	<0.001	0.478
	Gender	4.504	0.035	0.013
Interaction effect	Brightness * Texture * Gender	0.373	0.684	0.001
	Brightness * Texture	1.793	0.168	0.005
	Brightness * Gender	11.564	<0.001	0.033
	Texture * Gender	1.244	0.266	0.004

Table 18. Means and standard deviations of the brightness factor in the main-effect analysis.

Dependent Variable	Light-Toned Tiles		Medium-Toned Tiles		Dark-Toned Tiles	
	Mean	SD	Mean	SD	Mean	SD
Evaluation score of aesthetic comfort	1.164	0.01	0.997	0.012	0.916	0.013

Table 19. Means and standard deviations of the texture factor in the main-effect analysis.

Dependent Variable	Textured Tiles		Non-Textured Tiles	
	Mean	SD	Mean	SD
Evaluation score of aesthetic comfort	0.931	0.01	1.12	0.011

Table 20. Means and standard deviations of the gender factor in the main-effect analysis.

Dependent Variable	Male		Female	
	Mean	SD	Mean	SD
Evaluation score of aesthetic comfort	1.006	0.013	1.045	0.013

3.2.3. Evaluation Results of the Emotional Comfort Dimension

The brightness factor of ceramic tiles [$F(2, 680) = 153.315, p < 0.001, \eta^2 = 0.311$] and the texture factor [$F(1, 340) = 17.658, p < 0.001, \eta^2 = 0.049$] had significant main effects on emotional comfort scores, while the gender factor did not show a significant main effect [$F(1, 340) = 1.447, p = 0.23, \eta^2 = 0.004$]. Participants rated the emotional comfort of light-toned ceramic tiles (mean = 1.088) higher than medium- (mean = 0.978) and dark-toned ceramic tiles (mean = 0.869). Textured ceramic tiles (mean = 0.956) were rated lower in emotional comfort compared to non-textured tiles (mean = 1.000). Males rated the emotional comfort of ceramic tiles slightly higher (mean = 0.987) than females (mean = 0.969). There were no significant interaction effects among brightness, texture, and gender [$F(2, 680) = 0.734, p = 0.479, \eta^2 = 0.002$]. However, there was a significant interaction effect between brightness and gender [$F(2, 680) = 10.713, p < 0.001, \eta^2 = 0.031$]. Further results of the simple effect analysis showed a significant difference in emotional comfort scores for medium-toned ceramic tiles between males and females ($p = 0.003$), with males rating them higher (mean = 1.011) than females (mean = 0.945). There was also an interaction effect between texture and gender [$F(1, 340) = 5.73, p = 0.017, \eta^2 = 0.017$]. Table 21 presents the main and interaction effects. The means and standard deviations of the different factors are shown in Tables 22–24. Further results of the simple effect analysis indicated a significant difference in emotional comfort ratings for non-textured ceramic

tiles between males and females ($p = 0.023$), with males rating them higher (mean = 1.022) than females (mean = 0.978).

Table 21. Main and interaction effects of each factor in ANOVA results for the emotional comfort dimension.

Analysis Content	Independent Variable	F	<i>p</i>	Partial η^2
Main effects	Brightness	153.315	<0.001	0.311
	Texture	17.658	<0.001	0.049
	Gender	1.447	0.23	0.004
Interaction effects	Brightness * Texture * Gender	0.734	0.479	0.002
	Brightness * Texture	1.575	0.208	0.005
	Brightness * Gender	10.713	<0.001	0.031
	Texture * Gender	5.73	0.017	0.017

Table 22. Means and standard deviations of the brightness factor in the main-effect analysis.

Dependent Variable	Light-Toned Tiles		Medium-Toned Tiles		Dark-Toned Tiles	
	Mean	SD	Mean	SD	Mean	SD
Evaluation score of emotional comfort	1.088	0.009	0.978	0.01	0.869	0.012

Table 23. Means and standard deviations of the texture factor in the main-effect analysis.

Dependent Variable	Textured Tiles		Non-Textured Tiles	
	Mean	SD	Mean	SD
Evaluation score of emotional comfort	0.956	0.009	1.000	0.01

Table 24. Means and standard deviations of the gender factor in the main-effect analysis.

Dependent Variable	Male		Female	
	Mean	SD	Mean	SD
Evaluation score of emotional comfort	0.987	0.011	0.969	0.011

3.2.4. Total Evaluation Results for Visual Comfort

The brightness factor of ceramic tiles [$F(2, 680) = 549.052, p < 0.001, \eta^2 = 0.618$] and the texture factor [$F(1, 340) = 126.195, p < 0.001, \eta^2 = 0.271$] had a significant impact on the total visual comfort scores. The participants rated light-toned ceramic tiles (mean = 3.838) higher than medium-toned (mean = 3.242) and dark-toned (mean = 2.776) tiles. The scores for textured ceramic tiles (mean = 3.157) were lower than those for non-textured tiles (mean = 3.414). The gender factor did not have a significant main effect on overall visual comfort scores [$F(1, 340) = 0.742, p = 0.389, \eta^2 = 0.002$], with males rating the visual comfort of ceramic tiles slightly lower (mean = 3.268) than females (mean = 3.302). There were no significant interaction effects among brightness, texture, and gender [$F(2, 680) = 0.486, p = 0.613, \eta^2 = 0.001$]. However, there was an interaction effect between brightness and gender [$F(2, 680) = 4.387, p = 0.016, \eta^2 = 0.013$]. The main and interaction effects are detailed in Table 25. The means and standard deviations for the different factors are presented in Tables 26–28. Further results of the simple effect analysis indicated a significant difference in overall scores for dark-toned ceramic tiles between males and females ($p = 0.029$), with males rating them lower (mean = 2.706) than females (mean = 2.847).

Table 25. Main and interaction effects in ANOVA results for total visual comfort.

Analysis Content	Independent Variable	F	p	Partial η^2
Main effects	Brightness	549.052	<0.001	0.618
	Texture	126.195	<0.001	0.271
	Gender	0.742	0.389	0.002
Interaction effects	Brightness * Texture * Gender	0.486	0.613	0.001
	Brightness * Texture	1.407	0.246	0.004
	Brightness * Gender	4.387	0.016	0.013
	Texture * Gender	1.356	0.245	0.004

Table 26. Means and standard deviations of the brightness factor in the main-effect analysis.

Dependent Variable	Light-Toned Tiles		Medium-Toned Tiles		Dark-Toned Tiles	
	Mean	SD	Mean	SD	Mean	SD
Total evaluation score of visual comfort	3.838	0.023	3.242	0.024	2.776	0.032

Table 27. Means and standard deviations of the texture factor in the main-effect analysis.

Dependent Variable	Textured Tiles		Non-Textured Tiles	
	Mean	SD	Mean	SD
Total evaluation score of visual comfort	3.157	0.023	3.413	0.022

Table 28. Means and standard deviations of the gender factor in the main-effect analysis.

Dependent Variable	Male		Female	
	Mean	SD	Mean	SD
Total evaluation score of visual comfort	3.268	0.027	3.302	0.027

4. Discussion

The statistical results for the ceramic tile samples indicate that sample (d) received the highest overall average rating (3.949), suggesting that younger individuals generally experience greater visual comfort with light-toned, non-textured ceramic tiles. Sample (d) scored the highest across all three evaluated dimensions, indicating superior performance in terms of physiological, aesthetic, and emotional comfort. Additionally, ceramic tiles with the same brightness level exhibited minimal differences in the physiological comfort. The ratings for all samples revealed significant variations in visual comfort among different ceramic tiles. Therefore, designers can utilize these evaluations to understand specific users' visual comfort experiences with particular ceramic tiles.

Regarding the brightness factor of ceramic tiles, a multifactorial analysis of variance revealed that young university students rated light-toned ceramic tiles highest in overall and dimensional scores for visual comfort. Medium-toned tiles followed, while dark-toned tiles received the lowest ratings. These results suggest that light-toned ceramic tiles offer greater visual comfort in terms of physiology, aesthetics, and emotional responses compared to medium- and dark-toned tiles. This preference may be attributed to the bright, spacious, and pleasant experiences evoked by light-toned ceramic tiles [11]. According to the main-effect analysis, designers should prioritize light-toned ceramic tiles in spaces where visual comfort is crucial. Additionally, there was an interaction effect between brightness and

gender on aesthetic and emotional comfort, as well as overall ratings. Further results of the simple effect analysis showed that participants' aesthetic comfort ratings for dark-toned tiles and emotional comfort ratings for medium-toned tiles were influenced by gender. The interaction effect in the aesthetic comfort dimension revealed that males rated the aesthetic comfort of dark-toned ceramic tiles lower than females, indicating that women tend to provide higher aesthetic comfort ratings for medium-toned tiles. Conversely, in the emotional comfort dimension, males rated the emotional comfort of medium-toned tiles higher, suggesting that men perceive medium-toned tiles as more pleasant, intimate, calm, and relaxing than did women. Aside from the emotional comfort dimension of medium-toned tiles, females generally provided slightly higher ratings across physiological and aesthetic comfort dimensions for all types of ceramic tiles. These findings highlight that different demographic groups evaluate specific brightness levels of ceramic tiles differently across various dimensions. Therefore, designers should consider the characteristics of the user group when selecting medium- and dark-toned ceramic tiles.

Regarding the texture factor of ceramic tiles, the analysis of variance results showed that the young university students rated non-textured ceramic tiles higher in terms of overall visual comfort, aesthetic comfort, and emotional comfort, with no significant difference in physiological comfort ratings. This suggests that non-textured ceramic tiles are perceived as more aesthetically pleasing and emotionally satisfying than textured tiles. The lack of a significant difference in physiological comfort may be due to the fact that, while non-textured tiles provide a cleaner and more relaxing appearance, they do not markedly differ from textured tiles in terms of perceived temperature, brightness, spaciousness, and vitality. The interaction effect results indicated that in the emotional comfort dimension, males rated non-textured ceramic tiles higher than females, suggesting that non-textured tiles have a greater advantage in enhancing emotional comfort for male participants. Different texture levels of ceramic tiles exhibited varying strengths across different dimensions. Therefore, designers should consider the specific contexts and user characteristics when selecting ceramic tiles with different textures.

The main effect of the ANOVA results revealed no significant difference between males and females in the overall visual comfort ratings of ceramic tiles, with females' ratings being slightly higher. This indicates that the overall visual comfort scores of ceramic tiles were primarily influenced by the formal characteristics of tiles, with gender having an insignificant effect. However, the interaction effects among brightness, texture, and gender revealed that gender significantly affected the ratings of certain types of ceramic tiles. These results highlight both the commonalities in visual comfort ratings between male and female participants and the significant influence of gender on ratings of specific tile types (medium-toned and non-textured) in different dimensions (emotional, comfort, and aesthetic comfort). Therefore, designers should conduct targeted evaluations based on the specific needs of the interior space and the characteristics of the visual subjects.

From the merits of this research, first, in studies of the visual comfort of ceramic tiles, the Delphi method and AHP were used for the first time to establish an evaluation method including different dimensions and indicators. Designers can use this method to evaluate and compare different tiles in multiple dimensions. Second, by calculating the weight coefficient, the rationality of the proportion of the visual comfort evaluation index in the total score is strengthened. Third, statistical methods such as ANOVA were used to quantify the effects of factors such as tile brightness, texture, and participant gender on the evaluation scores of each dimension of tile visual comfort. For example, different from the previous two studies of the authors [14,15], this study not only includes an aesthetic perception evaluation of ceramic tiles, but also uses the Delphi method and AHP to construct different evaluation dimensions for visual comfort, adding important dimensions such as physiological comfort and emotional comfort. Compared with the research by Agost and Vergara [11], this study also adopted a variety of evaluation indicators in the questionnaire. Furthermore, this research assigns a corresponding weight coefficient to each indicator through calculations, so that the evaluation score of each indicator has an

appropriate proportion in the total score of visual comfort. In the selection of experimental materials, different from the study of Laparra et al. [16], this study divided experimental materials into more detail from the perspective of the brightness and texture characteristics of ceramic tiles, and explored for the first time the impact of participants' gender factor on the evaluation of visual comfort of ceramic tiles, filling the gap in the study of the impact of participants' characteristics on the perception of ceramic tiles. This study aimed to provide designers with an evaluation method to help them assess people's experiences with ceramic tiles. Future studies should include additional experiments and extensive surveys to further validate these findings.

5. Conclusions

This study established a method for evaluating the visual comfort of indoor ceramic tile designs, encompassing three dimensions: physiological, aesthetic, and emotional comfort. A combination of the AHP and the Delphi method was used to develop a visual comfort scale for ceramic tiles, which included three dimensions and twelve indicators. Weight coefficients for each visual comfort indicator were calculated, and a corresponding formula was formulated. Six different types of ceramic tiles were used as evaluation materials, and questionnaires were created based on the developed scale, yielding 342 valid responses. The multidimensional visual comfort scores for different tiles and the effects of tile brightness, texture, and participant gender on these scores were analyzed. The results of the sample analysis showed significant differences in visual comfort scores among the ceramic tile samples. ANOVA results indicated that, from the perspective of the commonality of the subjective evaluation results, both the brightness and texture of ceramic tiles have significant effects on their total visual comfort scores ($p < 0.001$; $p < 0.001$), with light-toned and non-texture ceramic tiles receiving the highest scores (mean = 3.949). From the perspective of the individual, while the gender factor did not significantly impact the overall visual comfort score, it did significantly impact certain dimensions for specific types of ceramic tiles. Men rated the aesthetic comfort of tiles lower than did women ($p = 0.035$), but rated the emotional comfort of medium-toned and non-textured tiles higher ($p = 0.003$; $p = 0.017$). Therefore, designers should conduct targeted evaluations based on the specific needs of the interior space and the characteristics of the visual subjects, selecting the appropriate tiles according to the evaluation results. These findings expand research methods for ceramic tiles, provide designers with an evaluation tool to understand the visual comfort of ceramic tiles, and present evaluation results specific to college students.

6. Limitation

The results of this study should be viewed with caution. In this study, the authors only explored the visual comfort evaluation of some Chinese college students on ceramic tiles. As some studies have shown [47,48], the individual characteristics of participants such as age and cultural background have impacts on perceptual evaluation. Therefore, people of different cultures and ages may have different views on the brightness and texture of tiles. Designers should take this into account when selecting ceramic tiles for different cultural backgrounds and different age groups. Furthermore, in future studies, more individual characteristics need to be included in the evaluation analysis. In addition, in order to avoid visual fatigue, only the brightness and texture of tiles, two important visual factors, were evaluated and analyzed in this study. The visual characteristics of ceramic tiles also include factors such as the degree of reflection and hue; these variables may also have an impact on the evaluation of visual comfort. Thus, more features of ceramic tiles need to be studied in the future. In addition, the subjective evaluation of visual comfort needs to be further supported by more physiological response studies, and the authors will apply more physiological research methods in future studies.

Author Contributions: Conceptualization, J.C.; methodology, J.C.; software, J.C.; validation, J.C. and Y.C.; formal analysis, Q.G.; investigation, J.C.; writing—original draft preparation, J.C.; writing—review and editing, J.C., Y.C. and Q.G.; visualization, J.C.; supervision, Y.C. and Q.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Science and technology research project of the Education Department of Jiangxi Province, grant number 191303.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy.

Acknowledgments: The authors thank all the participants for their active cooperation and the peer review experts for their advices.

Conflicts of Interest: The authors declare no conflicts of interest.

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