land

Article

Modeling the Effect of Greenways' Multilevel Visual Characteristics on Thermal Perception in Summer Based on Bayesian Network and Computer Vision

Yongrong Zheng, Siren Lan, Jiayi Zhao, Yuhan Liu, Songjun He and Chang Liu *

College of Landscape Architecture and Art, Fujian Agriculture and Forestry University, Fuzhou 350002, China; 1221775001@fafu.edu.cn (Y.Z.); lsr9636@fafu.edu.cn (S.L.); 5221726055@fafu.edu.cn (J.Z.); 5221726007@fafu.edu.cn (Y.L.); hesongjun@fafu.edu.cn (S.H.)
* Correspondence: 000q820075@fafu.edu.cn; Tel.: +86-159-8016-8525

Abstract: The aim of this study is to reveal the effects of multilevel visual characteristics of greenways on thermal perception in hot and humid regions during summer and to explore the potential of visual design to enhance psychological thermal comfort. Data on light (L), color (C), plant richness (PR), space openness (SO), scenic view (SV), thermal sensation (TS), and thermal preference (TP) were collected through questionnaires (n = 546). Computer vision technology was applied to measure the green view index (GVI), sky view index (SVI), paving index (PI), spatial enclosure (SE), and water index (WI). Using the hill climbing algorithm in R to construct a Bayesian network, model validation results indicated prediction accuracies of 0.799 for TS and 0.838 for TP. The results showed that: (1) SE, WI, and SV significantly positively influence TS, while L significantly negatively influences TS (R^2 = 0.6805, p-value < 0.05); (2) WI, TS, and SV significantly positively influence TP (R^2 = 0.759, p-value < 0.05).

Keywords: hot and humid areas; greenways; multilevel visual characteristics; thermal perception; bayesian network; computer vision; semantic image segmentation

check for updates

Citation: Zheng, Y.; Lan, S.; Zhao, J.; Liu, Y.; He, S.; Liu, C. Modeling the Effect of Greenways' Multilevel Visual Characteristics on Thermal Perception in Summer Based on Bayesian Network and Computer Vision. *Land* **2024**, *13*, 1796. https://doi.org/10.3390/land13111796

Academic Editor: Scott Hawken

Received: 24 August 2024
Revised: 3 October 2024
Accepted: 28 October 2024
Published: 31 October 2024

1. Introduction

A comfortable thermal environment is extremely important for the feel of an outdoor space [1]. A good feeling is an emotional response to the overall satisfaction and comfort of an outdoor space. In recent years, the urban thermal island effect has intensified and extreme hot weather is seriously affecting the urban environment and the health of urban residents [2]. In hot and humid areas, the comfort of the thermal environment greatly affects the physical and mental health of residents and their use of outdoor space [3]. Urban parks are the most frequently used and accessible green spaces for urban residents, and walking is one of the main purposes for which people use urban parks [4,5]. So, how to improve the thermal comfort of urban greenway environments and promote the maximization of the health effects of urban green space has become a difficult problem in the improvement and construction of thermal environments in urban green spaces [5–8].

Currently, the regulation of thermal perception relies mainly on the physical dimension to improve the climatic environment [9,10], but there is a relative lack of regulation of the psychological dimension. Environmental stimuli from different senses are known to promote psychological adaptation, and non-tactile stimuli significantly affect individual thermal comfort [11–13]. Among them, visual perception triggers more thoughts than other perceptions [14], and the abundance of visual stimuli in outdoor environments is closely related to people's thermal perception [15,16]. Studies have demonstrated that there is an association between visual characteristics, visual perception, and thermal perception [17–19], but the pathways through which multilevel visual characteristics influence thermal perception are not clear. Therefore, in this study, we extracted the visual–physical characteristics of the environment and utilized the method of picture comparison to relate the visual perceptual characteristics to thermal perception. To explore how different psychological perceptions arising from differences in visual characteristics modulate people's thermal perception, and to establish the relationship between the three dimensions of visual physical characteristics, visual perceptual characteristics, and thermal perception, we explored the pathways of visual characteristics' influence on thermal perception from the perspective of psychological modulation of perception.

In theoretical terms, this study explores the impact mechanism of visual characteristics on thermal perception, providing a theoretical basis for improving the thermal environment of urban green spaces from a visual design perspective. In terms of practical significance, it helps to expand the measures to address the urban heat island effect and promote the maximization of the health effects of urban green spaces. At the same time, in a social sense, it can improve the thermal comfort experience of urban residents, promote the frequency of use of urban green spaces, and encourage healthy outdoor activities.

2. Literature Review

2.1. Visual Perception

Humans rely on the body's own sense organs, namely, sight, hearing, touch, taste, and smell, to perceive the external environment [20]. Vision is the most direct way for people to feel the external environment, and 80% of external information is transmitted to the brain through the visual system [21]. Vision can trigger more thoughts in aesthetic activities than other perceptions, and it has a superiority that other perceptions cannot compare with [22]. From the physiological point of view, visual perception refers to the process in which light acts on the visual organs and forms a visual image after processing the stimulus through the visual system [21]. From the psychological point of view of visual perception, the elements are processed by the human brain to form the organization and understanding of external information, which helps people feel the stimulation of various elements in the environment [23]. The generation of visual aesthetic experience has at least three main processes: perception, cognition, and emotional processing [24]. When individuals analyze and understand visual images, perceptual and cognitive processes trigger emotional responses [25]. Individuals will have different understandings and experiences of different visual landscape characteristics, which will lead to significant differences in subjective evaluations and ultimately to making corresponding choices and behaviors [26–28].

2.2. Thermal Perception

Thermal perception refers to the conscious interpretation and elaboration of sensory data [29], which can be understood as the subjective satisfaction of the subject with the thermal environment, and consists of two main semantic dimensions: sensation and comfort. Thermal sensation (i.e., feeling warm, neutral, cold, etc.) is regarded as its objective or descriptive dimension and is most often assessed using the seven-point ASHRAE scale [30]. Thermal comfort is the emotional or enjoyment level of thermal perception and can be assessed using other terms related to comfort, such as thermal acceptability, thermal preference, or thermal pleasure [31]. An individual's sensory response to a thermal environment depends on seven variables such as air temperature, relative humidity, average radiant temperature, air velocity, physical activity, clothing, and time of day [32].

Factors Influencing Thermal Perception

Outdoor thermal comfort is influenced by a combination of physical, physiological, behavioral, and psychological factors [33]. Only 50% of the variance between objective and subjective thermal comfort assessments can be explained by physical and environmental factors, with the remainder attributed to psychological factors [34]. Psychological mechanisms have an important influence on thermal perception. Thermal adaptation and thermal expectations [35,36], thermal adaptation (physiological adaptation, psychological adaptation) [37], thermal history [38] or thermal experience (long-term experience, short-term experience) [39], climatic and cultural context [40–42], social characteristics [43], perceived control [44], duration of exposure [45], and environmental stimuli [46] influence people's psychological assessment of thermal environments.

Studies have shown that people's outdoor thermal sensations are influenced by the interactions between their short-term thermal history (e.g., time of exposure to the environment prior to the investigation) and their long-term thermal history (climatic context and acclimatization) [39]; cultural background is an important effect on thermal sensation [40]; there are differences in the thermal acclimatization processes among students in different climatic contexts [37]; perceived control is a key factor in adaptive thermal comfort modeling that reduces outdoor thermal sensitivity and makes participants more likely to have a comfortable thermal experience [44]; and physical and subjective attributes of a space can affect outdoor thermal comfort, such as landscape elements, luminous environments, and material colors have a significant effect on thermal perception [46]. In addition, people's social characteristics (gender, age, socio-economic status), cultural background, the climate they are used to, and thermal acclimatization measures all have an impact on thermal comfort [47,48]. Research on thermal acclimatization has explored how psychological factors affect thermal comfort and found that people living in hot and humid regions have a better tolerance for high temperatures than those living in low-temperature regions [49].

2.3. Visual and Thermal Perception

2.3.1. Pathways for the Formation of Thermal Perception with Visual Stimuli

Landscape cognition is the perception and awareness of landscape subjects regarding specific, objective landscape objects, also known as landscape "perception", which is characterized by the interaction of natural and man-made elements [50]. Human responses during perception include the following: sensation (environmental stimuli), perception (conscious interpretation and elaboration of sensory data), cognition (how to learn, remember, and think about information), emotion (conveying emotions), adaptation (physiological regulation), coping (psychological regulation), and behavior (activity, reacting, and action) [51].

According to the theory of human eyesight effect, the formation of thermal perception can be through the visual channel of the human eye (Figure 1). The visual signals transformed by two photoreceptor cells, the optic cone and the optic rod, are transmitted through layers and information processing to perceive the visual world, distinguish the type of objects, and feel comfortable in the visual environment [52]. Under visual stimulation, there are two pathways; one is the visual pathway "light—retina—visual crossover—lateral geniculate body—cerebral cortex—visual perception—mental adaptation—thermal sensation" [53–55]. The other is that visual stimulation by light produces a series of physiological responses that ultimately affect thermal sensation, i.e., "light-retina-hypothalamus-superior nucleus of the optic chiasm-pineal gland-melatonin-skin temperature, core temperature-thermal sensation" [56–58].

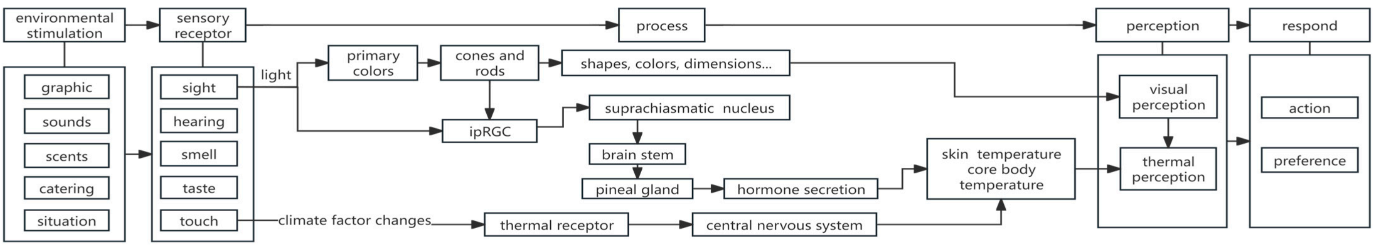


Figure 1. Pathways of visual–thermal perception influences.

2.3.2. The Influence of Visual Characteristics on Thermal Perception

Outdoor thermal comfort can be influenced by the visual effects of color, light intensity, and landscape attractiveness [59], as well as visually generated emotional and psychological states. One visual effect on hue perception is the Hue–Heat hypothesis. It suggests that color is related to temperature perception due to the psychological distinction between warm and cold colors, i.e., different colors of light or objects affect one's subjective perception of warmth and coldness [60–62]. Color temperature preference is a psychological response [63], different colors interfere to some extent with psychological and emotional states, and psychological significance can evoke a variety of emotions such as excitement, vitality, and calm [64]. A study showed that people felt thermal discomfort when spaces were "too wide", "too open", and composed of "cold" materials [65]. In another visual effect, visual cues from light influence thermal perception. In terms of subjective perception, the proportion of people who feel hot outdoors increases as the perception of sunlight increases [66]; there is a cross-modal effect of thermal perception, preference, and comfort polling on sun perception and sunlight preference under different sky conditions [17].

Landscape attractiveness and spatial characteristics also significantly influence thermal perception. Research in environmental psychology has shown that certain urban characteristics (e.g., building structure, color, greenery, building materials) strongly influence human aesthetic experiences and behavioral responses [47]. Perceptions of thermal comfort were also associated with naturalness, aesthetic ability, positive experiences of the environment [34,67,68], and satisfaction with landscape characteristics [46]. In aesthetically pleasing environments, people's overall comfort levels were consistently high [69]; in outdoor environments that are perceived as quiet and beautiful, humans have higher thermal tolerance and lower thermal sensitivity [11].

People's subjective responses to the outdoor thermal environment may be influenced by physical factors (temperature, velocity, humidity, radiation, etc.) and by the surrounding landscape (water, plaza, lawn, trees, etc.) [70]. There are significant associations between an individual's thermal and visual comfort in blue-green spaces and multiple environmental factors [71]. It is commonly believed that thermal comfort is higher in green environments than in other environments and that vegetation positively influences thermal comfort [72,73]. At the same climate level, places with higher green exposure show more positive thermal perceptions than places with higher building and sky exposure [74].

In addition, emotion was associated with subjective thermal perception [75,76] and emotion mediates the effect of landscape elements on thermal comfort [77]. When individuals reported negative emotions such as boredom, their thermal sensation vote was higher [78]. The psychological and emotional changes brought about by vision can have an impact on the perception of the thermal environment to a certain extent, and the use of good color design may lead to more positive emotions [79]. In summary, we can improve the visual physical characteristics to make people have different perceptions, at the psychological level, to regulate the thermal perception of people and to enhance the thermal comfort of the environment.

2.4. Methods for Assessing Thermal Perception with Visual Stimuli

The three main methods currently used to assess thermal perception through pictures as visual stimulus material are thermal perception maps, visual assessment of pictures, and picture comparison. Thermal perception maps are an alternative method of thermal perception assessment [80], by having participants indicate spatial areas on a map that would produce thermal perceptions, thus generating a map showing locations where most people would experience certain thermal perceptions [81]. A method of assessing thermal perception is based on the use of photographs to aid thermal perception measurement. Photographs can be used as stimuli in landscape analysis to study people's preferences related to certain characteristics of the landscape [82]. Visual assessment of photographs can help researchers understand how observable characteristics of the environment affect people's perception of microclimates [80]. Certain spatial characteristics can act as visual triggers for thermal comfort, and photographs can convey information about thermal discomfort memories. In this study, questionnaire respondents were presented with three photographs with different spatial characteristics under similar summer weather conditions. Respondents' choices of photographs were matched to previous answers on a thermal sensation assessment scale in the field. This reveals the possibility of using photographic comparisons as a complementary research method in outdoor thermal perception surveys. These studies have demonstrated the consistency between people's subjective assessments and objective field sensations of heat [83].

2.5. Research Questions and Objectives

Taking eight greenways in Fuzhou City, a city in a typical hot and humid region of China, as an example, the following three questions were proposed to be explored in this study:

- What visual physical characteristics affect thermal perception?
- What visual perceptual characteristics influence thermal perception?
- What are the pathways of influence of multilevel visual characteristics on thermal perception?

The objectives of this study were, first, to identify the key visual physical characteristics that influence thermal perception in outdoor walking environments; second, to understand how psychological and cognitive differences resulting from changes in visual physical characteristics affect thermal perception; and, finally, to construct a multilevel pathway for the influence of visual characteristics on thermal perception (Figure 2).

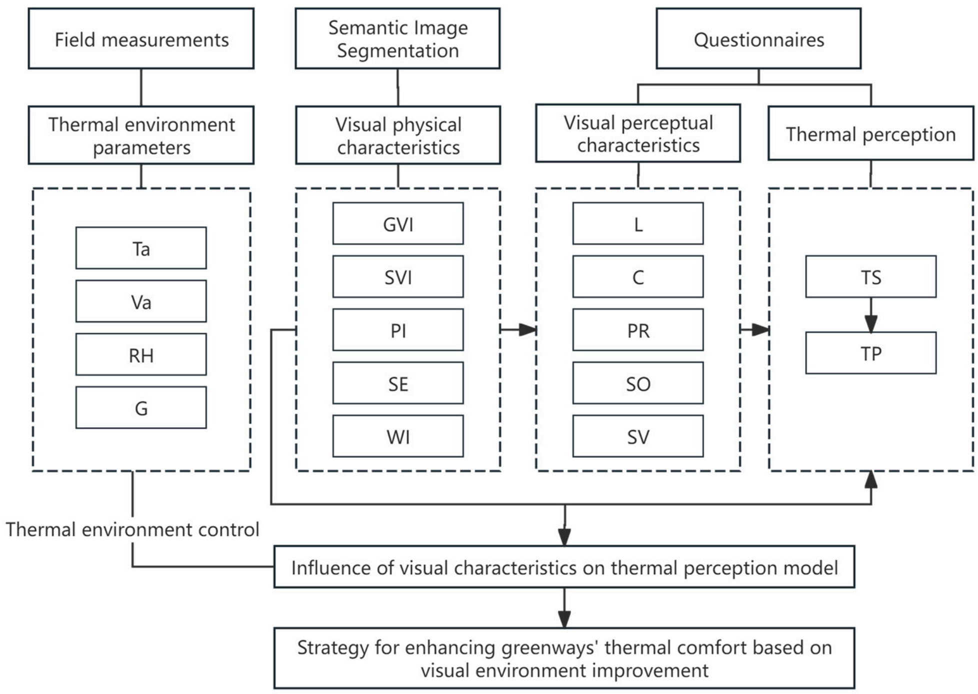


Figure 2. Research technology roadmaps.

3. Materials and Methods

3.1. Overview of the Study Area

Fuzhou (latitude: 26.08 N, longitude: 119.28 E) is located in Fujian Province on the southeast coast of China (Figure 3a). Fuzhou has a typical subtropical monsoon climate. Summer is long and winter is short, and summer is dominated by sunny and hot weather, with the annual extreme maximum temperature usually occurring in the summer months of July and August when the hottest monthly temperature averages 27–29 °C.

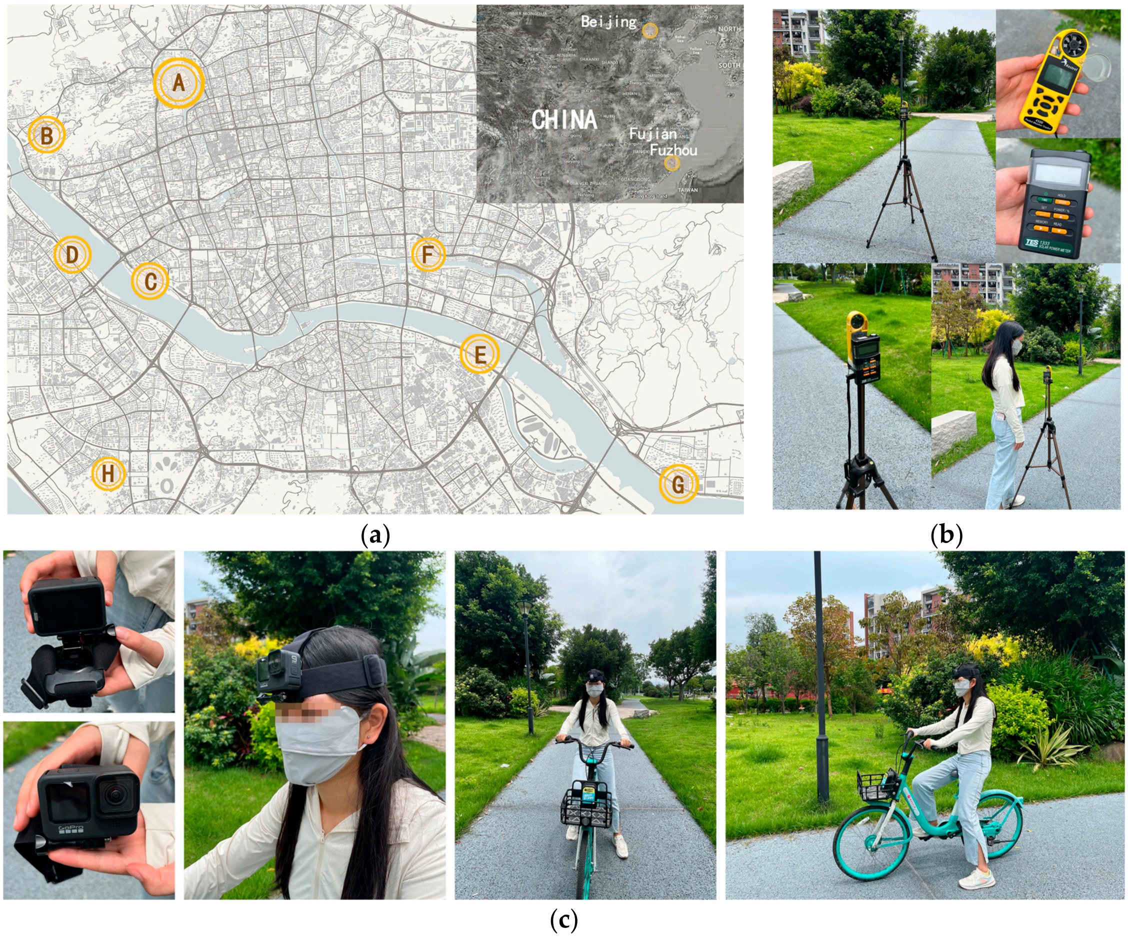


Figure 3. (**a**) A map of greenways in Fuzhou and location of Fuzhou in China; (**b**) thermal environment measurement; (**c**) video recording with GoPro.

Field Measurements

In this study, representative greenways in Fuzhou city area were selected, whose landscape space covered multiple types of visual characteristic scenes. In order to minimize subjective bias in the selection of greenways, three points are suggested as guidelines: (1) the selected walking routes should be representative of the entire walking environment of the area; (2) crossing driveways should be avoided for the maneuverability of the measurements; and (3) there should be obvious changes in the visual characteristics of the landscape at the measurement points. Twelve segments totaling 16,000 m of walking route and 120 measurement points were finally selected.

The measurement activity was carried out by 2 people at the same time, their route determined by the pre-survey, and the starting and ending points for the 2 people were kept the same. One of them mounted the Kestrel 5500 handheld weather meter and TES-1333 solar power meter (Table A1) on a tripod (Figure 3b), carried the equipment on foot along the route, and collected thermal environment data (temperature, humidity, wind speed, and solar radiation) at intervals of about 200 m. The sampling of the environmental data was set to 1 min, and the walking route was recorded using the Six Feet software (v. 4.202.23) during the collection process and fixed-point visual images of the collection point. Another person wore a GoPro camera with a fixed clip headband in the head position to record video while riding, and to prevent the effects of tilt or shake set the camera mode to linear + horizon function and the video format to 4 k/60 fps (Figure 3c).

The measurement activity lasted for 8 days, from 5 July to 13 July 2023, and was conducted from 8:00 to 11:30 a.m. This is the time period when greenways are most frequently used by people in hot and humid areas, and it is also the time period when the weather is clear and the light and weather conditions are relatively stable, which reduces the interference of other factors as well as the visual impacts caused by differences in light. The thermal environment parameters were generally consistent during the control measurements to ensure that there were no significant differences in solar altitude, atmospheric visibility, and weather conditions to exclude the perceptual effects of differences in picture taking (Table A2). The recorded video was converted to pictures using the Free Video to JPG Converter software (v. 5.0.101.201), outputting one picture per second with a converted picture resolution of 3840 × 2160. We screened out the pictures corresponding to the fixed-point pictures recorded by the Six Feet software. To ensure the quality of the pictures, 19 measuring points with poor light conditions or insignificant changes in landscape characteristics before and after were screened out, and 101 measuring points were finally retained (Table 1).

Table 1. Description of study sites.

Location		Site Description	Number of Points
West Lake Greenway (A)		Section A is mainly for the West Lake Park internal lake walkway, road width 2–4 m, to stone road, wooden trestle mainly.	Measurement: 17 Reservations: 12
Fudao (B)		Section B relies on the mountain to form a panoramic walkway, with a road width of 2.4 m and a steel skeleton walkway as its main characteristics.	Measurement: 15 Reservations: 15
North Riverside Greenway (C)		Section C is located on the north bank of the Min River, with a road width of 3 m, made of gray asphalt, bluestone slabs, and wood.	Measurement: 14 Reservations: 12
Nantai Island Greenway	South Riverside Greenway (D)	Section D connects residential areas and parks, with a road width of 3 m, and the road material is mainly permeable bricks.	Measurement: 14 Reservations: 12
	Flora Greenway (E)	Section E of the Flora Greenway is an integral part of the levee, with a road width of 5 m and a paving material of mainly blue asphalt.	Measurement: 14 Reservations: 12
Bright Harbor Greenway (F)		Section F links residential areas and parks, with a road width of 5 m and paving materials of mainly red asphalt and bluestone slabs.	Measurement: 20 Reservations: 15
East Riverside Greenway (G)		Section G belongs to the north bank of the Min River, road width of 3 m, paving materials are mainly grey asphalt, green stone slabs.	Measurement: 15 Reservations: 14
Feifeng Mountain Greenway (H)		Section H is in the park's internal ring of mountain greenways, road width of 6 m, paving material of gray asphalt.	Measurement: 12 Reservations: 8

3.2. Variables and Measurement

3.2.1. Visual Physical Characteristics

When quantifying the visual physical characteristics of greenways, Semantic Image Segmentation (SIS) is an important technique for recognizing and understanding the content of images at the pixel level using computers, which can effectively extract landscape elements from images [84]. This study used the Pyramid Scene Parsing Network (PSP-Net) semantic segmentation model for semantic segmentation of images. A dataset ADE20K containing 27,000 images and more than 3000 object categories was selected. A total of 12 categories of landscape characteristic elements in the greenway pictures was extracted, and the percentage of different elements in the pictures was calculated. We integrated them into 5 indicators of visual physical characteristics of the greenway: GVI, SVI, PI, SE, WI. The formula for calculating the indicators is as follows (Equations (1)–(5)).

$$SVI = Asky/Atotal \times 100\% \quad (1)$$

$$GVI = (Atree + Agrass + Aplant)/Atotal \times 100\% \quad (2)$$

$$PI = (Aroad + Asidewalk + Aearth + Apath)/Atotal \times 100\% \quad (3)$$

$$SE = (Atree + Aplant + Afence + Arailing + Astreetlight)/Atotal \times 100\% \quad (4)$$

$$WI = Awater/Atotal \times 100\% \quad (5)$$

where $Atotal$ is the total number of pixels of the image, and Ax represents the number of pixels occupied by each element.

3.2.2. Visual Perception Characteristics

Through the literature review, five visual perception characteristics were compiled, including color (C), light (L), plant richness (PR), space openness (SO), and scenic view (SV). C refers to the perceived temperature associated with color, which is the subjective assessment of the greenway landscape's thermal environment based on the visual stimulation of colors. It indicates whether the overall environment feels warm or cold, and whether the sensation leans more towards warmth or coolness. L is determined by the light reflected or transmitted by the color, indicating the degree of light and darkness of the color. In this paper, the light is the degree of ambient light and darkness presented by the picture scene. PR refers to the richness of the plant configuration in the picture scene, which is evaluated in terms of the number of plant species, hierarchical structure, color composition, spatial form, etc. SO is the proportion of the "empty" area within the visible field of view (the sky and the unobstructed ground) to the area of the field of view. SV refers to the aesthetic and ecological perspective, from the landscape elements, to judge the scenery beautiful or ordinary.

3.2.3. Thermal Perception Variables

Thermal perception measures consist of two indicators: thermal sensation (TS) and thermal preference (TP). TS typically represents the human body's perception and sensation of environmental temperature across various conditions. However, this study specifically examines how visual characteristics influence thermal sensation, assessing whether a visual scene, under the influence of visual stimuli, is perceived as cool or hot in terms of thermal comfort. TP usually refers to an individual's preference and comfort under different thermal environmental conditions, while the thermal preference in this study focuses on an individual's thermal environmental sensation of a picture scene's Preference.

3.2.4. Questionnaires

The questionnaire contains three parts: individual factors, visual perception evaluation, and thermal perception evaluation. Individual factors include demographic issues and issues of thermal experience. The purpose of this section was to understand the individual differences that may have an impact on thermal perception and whether the respondent had experience moving around the greenway space and was able to make an assessment of the visual perception of the environment and thermal perception through picture stimuli. The visual evaluation part consists of five perception indicators, L, C, PR, SO, and SV. Thermal perception contains two indicators, TS and TP.

Photo comparison can assist thermal perception measurement [83]. In this study, one picture was selected as the benchmark picture for visual perception and thermal perception evaluation, and respondents assessed visual and thermal perception by comparing other pictures with the benchmark picture. The benchmark picture was selected by ordering the five physical characteristic indicators, GVI, SVI, PI, SE and WI, from largest to smallest, and selecting a picture with each indicator in the range around the median. Finally, a picture that was relatively in the middle of all five metrics was determined as the benchmark picture. The remaining 100 pictures except the benchmark picture were randomly divided into 10 copies, with 10 pictures as a group to form 10 parallel questionnaires. A five-point Likert scale was used with visual perception indicators and thermal perception indicators described by 7 groups of relative adjectives, with 1 to 5 representing very below the benchmark picture, relatively below the benchmark picture, almost the same as the benchmark picture, relatively above the benchmark picture, and very above the benchmark picture, respectively (Table 2).

Table 2. Subjective perception questions for thermal and visual perception.

Perception	Questions
Visual perception	
Overall environment light (L)	1. What do you think of the overall environment light of the right picture compared to the left picture? Much darker, darker, moderate, brighter, much brighter.
Overall color tone (C)	2. What do you think of the overall color tone of the right picture compared to the left picture? Much colder, colder, moderate, warmer, much warmer.
Plant richness (PR)	3. What do you think of the abundance of plants in the right picture compared to the left picture? Much more monotonous, more monotonous, moderate, richer, much richer.
Space openness (SO)	4. What do you think of the openness of space in the right picture compared to the left picture? Much more closed, more closed, moderate, more open, much more open.
Scenic view (SV)	5. What do you think of the scenic view in the right picture compared to the left picture? Much more common, more common, moderate, more beautiful, much more beautiful.
Thermal perception	
Thermal sensation (TS)	6. How do you think the temperatures on the right look in the summer compared to the left graph? Much hotter, hotter, moderate, cooler, much cooler.
Thermal preference (TP)	7. Which scene do you prefer for the feeling of a hot environment? Left, right.

Questionnaires were designed based on the Sojump platform (https://www.wjx.cn/, accessed on 23 August 2024), and the corresponding QR codes of the questionnaires were scanned to answer the questions through social networks, offline surveys, etc. Most of the questionnaires were disseminated in the form of snowballing, and a few were disseminated through the Internet. Ten sets of parallel questionnaires were distributed, totaling 700 copies; 682 copies were recovered, including 136 invalid questionnaires and 546 valid questionnaires, with an effective index of 78%, and the number of valid questionnaires recovered for each questionnaire was more than 45. An alpha reliability test was performed on the recovered questionnaires and the Cronbach's alpha coefficient for each set of questionnaires was greater than 0.87.

3.3. Data Analysis Methods

Bayesian networks have reasoning models similar to those used by humans to accomplish everyday reasoning [85], that is, capable of learning and reasoning under conditions of incomplete and uncertain information, capturing the correlations between individual information elements and the uncertainty of these relationships, and constructing physically meaningful network models.

The construction of the model was based on the R language (v. 4.4.0) and consisted of four main steps: first, a preliminary exploration of the data was performed to identify possible relationships between variables by testing the normality of the data and the Spearman correlation of the variables. Based on the preliminary exploration, we introduced a priori knowledge to define the hypothesized relationships between variables and construct the primary network structure. Next, the average network was computed by relearning the Bayesian network by playback sampling each sample to learn the model structure. The arc intensity distribution in the visualized network was visualized and high-frequency and high-intensity arcs were filtered into the final simplified network. The third step utilized the lm () function to fit the linear structure of the simplified network. Fourthly, cross-validation based on the maximum likelihood method was performed to measure the accuracy of model prediction, and loss function was calculated to judge the model effect.

4. Results

4.1. Descriptive Statistics

4.1.1. Sociological and Behavioral Characteristics of Populations

Of the 546 samples obtained, the respondents were 45.8% male and 54.2% female; the age composition was dominated by young and middle-aged people aged 19–35, accounting for 87.2% of the total, with fewer respondents in other age groups; the education level was dominated by secondary education, accounting for 95.2% of the total; in terms of the occupational composition, 70.1% of the respondents were students, with fewer in other occupations; and in terms of the income composition, the number of people at the CNY 0–3000 low-income level was the largest (Table 3).

Table 3. Sociological characterization of the sample population.

Variable	Form	Percentage
Gender	Male	45.8%
	Women	54.2%
Age	18 years and under	5.68%
	19–35 years	87.18%
	36–65 years	6.96%
	66 and over	0.18%
Educational level	Primary and below	0.4%
	Junior high school, high school	95.2%
	College, Bachelor's Degree, Master's Degree, Doctorate	4.4%
Careers	Teacher/Administration	5.6%
	Design practitioner	4.0%
	Liberal profession	3.1%
	Student	70.1%
	Marketing/Sales/Commercial	4.0%
	Other	13.2%
Salary	CNY 0–3000	70.3%
	CNY 3000–5000	11.5%
	CNY 5000–10,000	12.3%
	More than CNY 10,000	5.9%

4.1.2. Thermal Experience

The statistical results show that 90.5% of the respondents had lived in the Fujian area; 82.2% of the respondents thought that the climate in their living area in the last three years was hot, 17% thought that it was mild, and only 0.7% thought that the climate was cool; 87.4% of the respondents had the experience of using the greenways during the summer months; 75.6% of the people had been active in the parks for more than 0.5 h; and the respondents' main greenway activity was recreational walking, with a few choosing to do fitness exercise, cycling and sightseeing, recreational activities, and other activities on the greenways (Table 4). The results of the survey showed that most of the respondents were from the study area, had experience on the greenways, and possessed experiential perceptions of greenway environments and were able to assess visual and thermal perceptions through picture stimuli.

Table 4. Characterization of sample thermal experience.

Variable	Form	Percentage
Climate in the living area	Cool	0.7%
	Mild	17%
	Hot	82.2%
Life experience in Fujian	Yes	90.5%
	No	9.5%
Experience of using greenways in summer	Yes	87.4%
	No	12.6%
Duration of activities on the greenway	0–0.5 h	24.4%
	0.5–1.0 h	42.9%
	1.0–2.0 h	26.2%
	2.0 h or more	6.6%
Type of activity	Leisurely stroll	52.7%
	Physical exercise	16.0%
	Bicycle sightseeing	15.4%
	Entertainment	11.0%
	Other	5.0%

4.1.3. Thermal Environment and Visual Physical Characteristics

During the field measurements, the weather conditions were hot and sunny. The temperatures of the eight greenways were in the hot summer range, the humidity was in the humid to wetter range, and the average wind speeds during the measurement period were in the range of 0.3–1.5 m/s (Table A3), ensuring that the thermal environmental conditions were essentially the same during the image collection process. Semantic segmentation of the 101-image dataset revealed that seven landscape elements, namely, roads, sidewalks, buildings, walls, vegetation, greenbelts, and sky, were the main components of the visual-physical characteristics of the greenways (Table A4).

According to the calculation formula (Equations (1)–(5)) integrating landscape elements into five visual physical characteristic indicators, the GVI, SVI, PI, SE, and WI of each greenway were taken as the mean values. It can be seen (Figure A1) that the overall SE level of section B was the highest; the SVI levels of sections A, E, and G were higher; the overall PI level of section A was relatively low, and those of section E and section F were higher; the GVI of sections C, D, F, and G were higher; among them, the GVI level of section C was the highest and section B was the lowest. The percentage of greenery was the main influence on the SE level, and the lower GVI but higher SE level of section B may have been related to the characteristic of this greenway being built on the mountain. The overall percentages of WI in the greenways were all low, with section A being a typical lake-type greenway with a relatively high percentage of WI.

4.2. Perception Evaluation

4.2.1. Rater Agreement Index

A rater consistency test was performed for each question of the questionnaire, and perceptual ratings were averaged only when the index of each picture had consistent and high confidence in that picture [86]. Generally speaking, the index consistency index Rwg is considered to be moderate when its value is greater than 0.7. The content of the survey in this study was subjective perception, with some differences in individual ratings, so that more than half of the people in the same group having consistent evaluations (i.e., Rwg > 0.5) can be considered to show consistency in the evaluations of individuals in the group for the pictures. After the test, 17 pictures that did not meet the consistency test were excluded, and the perceptual evaluations of the remaining 83 pictures were averaged.

4.2.2. Overall Perception

The eight greenways' L ratings were between 2.00 and 4.26, with section B having the lowest mean rating, and sections G and H relatively high; C ratings were between 2.02 and 4.07, with a large span in the distribution of rating levels for sections B, D, F, G, and H ratings being relatively centralized and high, and section A having a lower color rating; PR overall ratings were between 2.20 and 4.37, with a more pronounced difference between greenways with more significant differences between them, with E and G being relatively low, the rest of the ratings being above moderate levels, and section F being the highest; SO ratings ranged from 2.12 to 4.49, with greater differences in ratings between greenways, with B being low, the rest of the ratings being above moderate levels, and section G being the highest; and SV ratings ranged from 2.45 to 4.11, with a relatively large span of distribution of ratings in B and C, and the rest of the greenways being relatively centralized in their rating levels; TS scores ranged from 2.30 to 4.26, with section G scores low, A, D, and F scores high, and B, C, E, and H moderate (Figure A2).

4.2.3. Influence of Individual Factors on Thermal Perception

Individual factors were analyzed by ANOVA with TS and TP, respectively. There was a significant difference in thermal sensation scores by gender and salary level (Table 5). The results showed that females had slightly higher thermal sensation scores (mean = 1.73) than males (mean = 1.71), and that females had better thermal sensation in the same visual situation. Salary level did not pass the Homogeneity of Variance Test, and a Welch ANOVA was performed on this set of variables. The results showed a significant difference in thermal sensation scores for different wage levels ($p = 0.004 < 0.05$). Tambane's T2 test was conducted and those with income levels of CNY 0–3000 had lower thermal perception scores than those with income levels of CNY 5000-10,000 (Table 6).

Table 5. Variance analysis of thermal perception.

	Thermal Sensation		Thermal Preference	
Variable	**Homogeneity of Variance Test** [1]	***p*** [2]	**Homogeneity of Variance Test** [1]	***p*** [2]
Gender	0.956	0.048	0.260	0.089
Age	0.387	0.071	0.275	0.704
Educational level	0.394	0.790	0.478	0.727
Salary	0.018	0.016	0.505	0.730
Careers	0.092	0.066	0.262	0.989
Climate in the living area	0.180	0.072	0.302	0.513
Life experience in Fujian	0.671	0.476	0.990	0.063

Table 5. *Cont.*

	Thermal Sensation		Thermal Preference	
Variable	**Homogeneity of Variance Test** [1]	p [2]	**Homogeneity of Variance Test** [1]	p [2]
Experience of using greenways in summer	0.970	0.100	0.010	0.575
Duration of activities on the greenway	0.172	0.147	0.927	0.408

[1] Homogeneity of variance test ($p > 0.05$); [2] $p < 0.05$.

Table 6. Tambane's T2 test.

(I) Salary (CNY)	(J) Salary (CNY)	Mean Value Difference (I–J)	p [1]
0–3000	3000–5000	−0.04761	0.453
	5000–10,000	−0.09755	0.002
	More than 10,000	−0.02474	0.995
3000–5000	5000–10,000	−0.04994	0.618
	More than 10,000	0.02287	0.998
5000–10,000	More than 10,000	0.07281	0.596

[1] $p < 0.05$.

4.3. Model Construction and Validation

4.3.1. Data Exploration

The inference process of a Bayesian network relies on the distribution characteristics of the data, the distribution characteristics of the data will affect the stability of the Bayesian network, and the construction of the Bayesian network in this study was based on the existence of linear relationships between the nodes; if the data obey the normal distribution, then the assumption of linear relationship may be more reasonable, and the normality of the data also affects the interpretation of the results of the correlation analysis and the reliability of the correlation analysis.

Using the toolkit "magrittr", "dplyr", the mutate () function was used to convert discrete data to numerical data. hist (), lines (), and curve () functions were used to plot histograms, kernel density estimation curves, and normal distribution curves to complete the normality test. Our study was based on the R language and the normality test was performed on the data before constructing the model. None of the 12 variables conformed to the normal distribution (Figure A3). Spearman's correlation analysis was performed using the pairs (), setdiff () functions to plot the scatterplot matrix. This is a non-parametric correlation analysis method based on the ordering of the variables rather than the original values and is therefore not sensitive to the distribution of the data. As can be seen in Figure 4, there was a partial linear relationship between the variables, and based on this result we hypothesized a preliminary undirected network structure.

4.3.2. Model Structure Learning

Due to the complexity of the initial structure constructed by correlation, the model structure needed to be further optimized by structure learning and parameter learning. In this study, a structure learning method based on the dependency relationship between nodes was adopted [87,88]. In this study, a priori knowledge was introduced to improve the efficiency of Bayesian network construction. The a priori knowledge consisted of a "blacklist" and a "whitelist", where the blacklist referred to arcs that were known not to exist, and the whitelist referred to arcs that were known to exist. Incorporating a priori knowledge into the learning of the network structure reduces the difficulty, and accelerates the speed of finding the best-fitting network structure [89]. In this study, correlations between visual physical characteristics metrics were included in the blacklist, and metrics for which relationships were hypothesized to exist were included in the whitelist (Table 7). The toolkit "bnlearn" was installed for Bayesian network learning and inference, and "Rgraphviz" for visualizing the network structure.

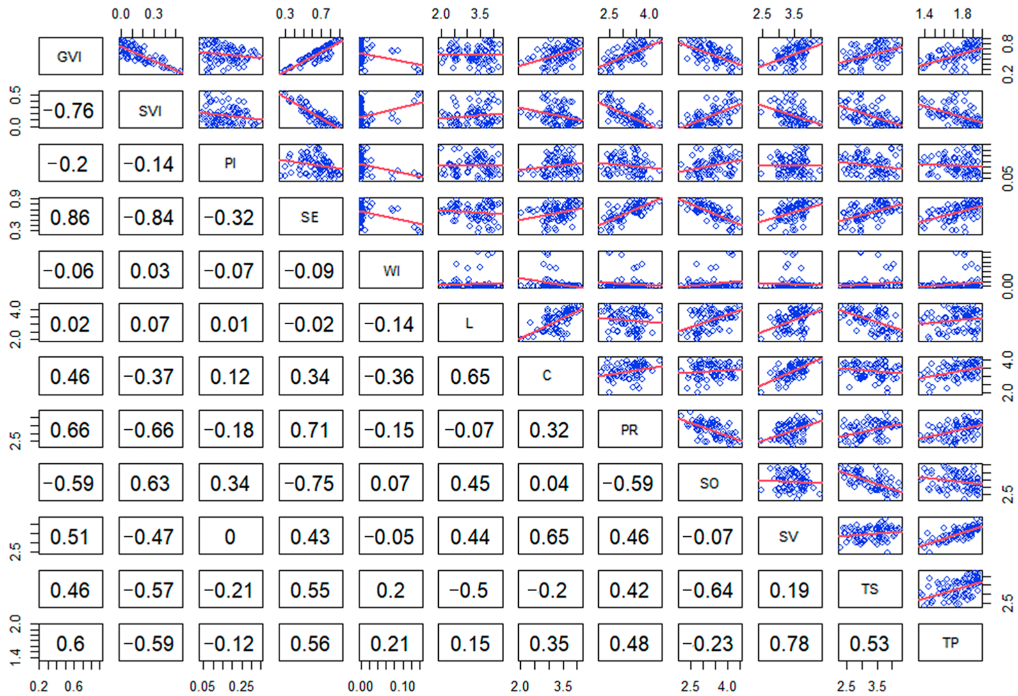


Figure 4. Visualization of linear correlation between visual characteristics and thermal perception.

The blacklist and whitelist data frames were created to define the black- and whitelists, and the hc () function was used to perform a hill climbing algorithm to find the best Bayesian network for constructing the directed acyclic graph DAG (Figure 5a). Since the variables did not all conform to a normal distribution, it was not possible to determine the strength of the relationship between the arcs in the network structure. Therefore, we resampled the data using the playback sampling method, applying blacklist and whitelist constraints to each sample of the relearned Bayesian network. The robustness of the network structure was evaluated using the boot.strength function. The resampling parameter was set to 200 times, the algorithm was defined as "hc" for structure learning, and the algorithm.arg function passed the black- and whitelists as parameters for structure learning. Finally, the average network structure was calculated by the averaged network function.

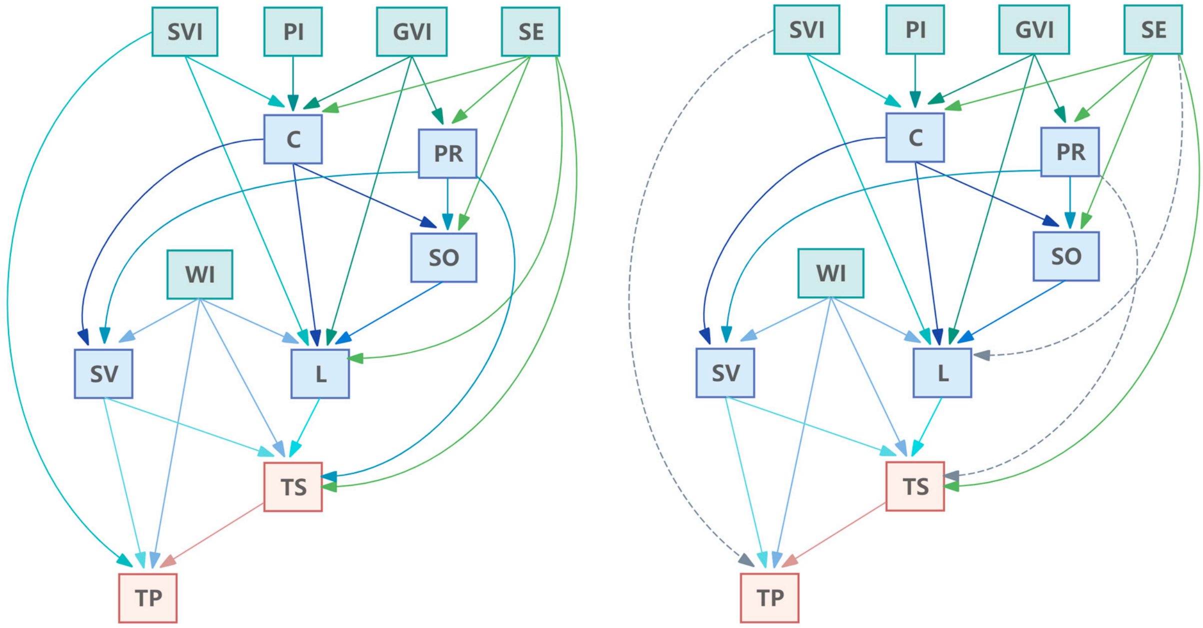
Table 7. Blacklist and whitelist definitions.

Blacklist		Whitelist	
From	**To**	**From**	**To**
GVI	SVI	GVI	C
	SE		L
	PI		PR
	WI	SVI	C
SVI	GVI		L
	PI		TP
	SE	PI	C
	WI		SO

Table 7. *Cont.*

Blacklist		Whitelist	
From	**To**	**From**	**To**
PI	GVI	SE	C
	SVI		L
	SE		PR
	WI		SO
SE	GVI		TS
	SVI	WI	C
	PI		L
	WI		SV
WI	GVI		TS
	SVI		TP
	PI	L	TS
	SE	C	SO
			L
			SV
		PR	SO
			SV
		SE	C
			SO
			PR
			TS
		SV	TS
			TP

The cpdag function was used to estimate the conditional independence from the directed acyclic graph (DAG), the black- and whitelists were set to the structure learning of the averaged network, the undirected arcs were extracted from the given preliminary network, the possible undirected edges were deduced based on the directed arcs' directionality and intensity, and the average arc intensity threshold was computed to be 0.46. The plot () function was applied to visualize the distribution of the arc intensities in the network. The threshold parameter in the averaged network function was set to 0.9 to filter out the arcs with high frequency and intensity greater than 0.9 into the final simplified network (Figure 5b). The dashed line indicates the unstable connected arcs removed from the final simplified network relative to the preliminary network.



(**a**) (**b**)

Figure 5. (**a**) Primary Bayesian network structure; (**b**) influence of visual characteristics on thermal perception model.

4.3.3. Model Fitting

The following model was obtained by fitting the linear structure in the network using the least-squares-based lm () function (Equations (6)–(12)). The degree of fit of the linear equations can be expressed by the goodness of fit (R-squared), and the F-test is used to assess the fit of the model, with larger values indicating a better fit of the model. The *p*-values of the equations were all less than 0.05, and all seven equations passed the significance test (Table 8).

$$TP = 0.61571 + 0.83805 \times WI + 0.34571 \times SV + 0.11458 \times TS \tag{6}$$

$$TS = 2.48557 + 1.63004 \times SE + 5.37333 \times WI - 0.50877 \times L + 0.39594 \times SV \tag{7}$$

$$L = -1.235734 - 0.009069 \times GVI + 2.906992 \times WI + 0.135881 \times SVI + 0.429254 \times SO + 0.903788 \times C \tag{8}$$

$$C = -1.6293 + 4.7397 \times SVI + 3.2903 \times SE + 4.8465 \times PI + 2.1224 \times GVI \tag{9}$$

$$PR = 1.6887 + 1.9561 \times SE + 0.4551 \times GVI \tag{10}$$

$$SO = 4.24213 - 2.57524 \times SE - 0.25200 \times PR + 0.47442 \times C \tag{11}$$

$$SV = 1.04165 + 2.00634 \times WI + 0.49522 \times C + 0.23200 \times PR \tag{12}$$

Table 8. Fit and F-test results of linear equations.

Linear Equation	R-Squared	F-Statistic	*p*-Value [1]
(6)	0.759	82.94	0.000
(7)	0.6805	41.54	0.000
(8)	0.6158	24.68	0.000
(9)	0.375	11.7	0.000
(10)	0.5462	48.15	0.000
(11)	0.6963	60.37	0.000

[1] $p < 0.05$.

4.3.4. Model Validation and Prediction Accuracy

Parameter learning was performed using the bn.cv function based on maximum likelihood estimation to perform cross-validation of the simplified network. The "hc" algorithm was used to learn the structure of the network and calculate the prediction loss for each variable. The parameters were set to n = 83, runs = 35, and the dataset was randomly partitioned 83 times for 35 training and validation runs. In each validation, one of the subsets was used as the test set and the rest were used as the training set. After completing n training and validation runs, the overall prediction accuracy of the model was evaluated using the average loss. The loss function "cor-wl" was specified through the loss parameter to determine the model effectiveness. Since the loss function predicts the value of each node only from their parents, which is meaningless when dealing with nodes with few or no parents, the predictions were targeted at variables where parents existed. The crossover results showed that the accuracy of all seven nodes was greater than 0.7, with L, C, SO, SV, and TP being able to predict with an accuracy of 0.8 or more (Table 9).

Table 9. Influence of visual characteristics on thermal perception model's prediction accuracy.

	L	**C**	**PR**	**SO**	**SV**	**TS**	**TP**
Accuracy	0.829	0.811	0.716	0.846	0.855	0.799	0.838

In addition, we found significant differences between the effects of gender and salary on thermal sensation. Constructing the model by grouping the genders and obtaining a structure consistent with the overall model proved that the model we constructed was stable across genders. Salary levels differed only in the two groups, which may have been related to the fact that some of the data recovered were in the student group, and those who had no income among them should be removed before making comparisons. Therefore, it was treated as an irrelevant variable in this study.

5. Discussion

5.1. Multilevel Visual Characteristics and Thermal Perception

5.1.1. Associations Between Multilevel Visual Characteristics

The Bayesian network structure constructed in this study showed that SVI, PI, GVI, and SE significantly and positively affected C (Equation (9)). Physical characteristic elements are the main components of the picture scene, and the picture color is presented by several elements, which was verified in our study. PR was positively influenced by GVI and SE (Equation (10)), and green view index and spatial enclosure determined the perception of plant richness.

Among the indicators at the visual perception level, C and PR are only influenced by visual physical characteristics, and both act as mediators with other physical characteristics to influence L, SO, and SV. WI, SVI, C, and SO positively influence L, and GVI negatively influences L (Equation (8)), and the higher sky view index laterally reflects the higher space openness of the environment, and the higher intensity of the light received in the field environment; the greenway segments of research area containing water index are usually waterfront areas with more open views and a higher perception of brightness. Different sky conditions influence sunlight perception and preference [17], as was seen in our findings. Whereas GVI reflects the degree of greening of the greenways, more vegetation has a stronger shading effect on light, resulting in lower brightness perception. Previous studies have shown that seasonal characteristics of trees have a significant effect on visual light perception [19], and our study reached a consistent conclusion.

SE and PR negatively affect SO, and C positively affects SO (Equation (11)). Spatial enclosure and plant richness perceptions reflect the degree of greenway greening; the more vegetation, the stronger the enclosing and shading effect on the space. C is influenced by multiple physical characteristics, representing the warmth or coolness of the overall environmental tone. The higher the sky view index, the stronger the lighting, and the warmer the hue presented by the visual scenes, the more open the space feels. WI, C, and PR positively influence SV (Equation (12)). The higher the water index, color perception, and plant richness, the higher the perceived beauty of scenic view. It has been mentioned that building structure, color, greenery, and building materials can strongly affect human aesthetic experience and behavioral responses [47]. This is consistent with our findings.

In the initial hypotheses, we assumed that PI would influence SO, SE would influence L, WI would influence C, and SVI would influence PR, but the initial model eliminated the association of WI with C and SVI with PR, and the final simplified model eliminated the effects of PI on SO and SE on L. This may have been due to the fact that fewer water elements were found in the greenway environment during the data collection process; most of the PIs found were paving materials, and there were fewer differences in hard paving materials and roadway widths among the several greenways surveyed, which may have led to weaker correlations between PI and other variables.

5.1.2. The Effect of Multilevel Visual Characteristics on Thermal Perception

Our results show that SE, SV, and WI significantly and positively affect TS, and L significantly and negatively affects TS (Equation (7)). The higher the degree of spatial enclosure, water index, and scenic view, the cooler the thermal sensation of the visual environment, and the higher the brightness, the hotter the thermal sensation. Enhancing the degree of thermal sensation coolness of the visual environment can be achieved by decreasing the lighting and enhancing the percentage of water index, the spatial enclosure, and the degree of aesthetic beauty of the environment. The results of the thermal preference survey indicated that greenway spaces with a larger proportion of water space, higher aesthetic beauty, and cooler thermal sensations were more popular, with WI, TS, and SV significantly and positively influencing TP (Equation (6)). Among them, SV was positively influenced by WI, PR, and C, SE and GVI positively influenced PR, and GVI negatively influenced L. Therefore, increasing the water index at the level of visual physical characteristics can directly promote thermal sensation enhancement. At the same time, increasing the water index, spatial enclosure, and green view index is conducive to aesthetics, which contributes to the thermal sensation of the visual environment. The enhancement of the water index, the beauty of the scenic view, and the thermal sensation promotes the degree of preference as well as the use of the greenways.

Previous findings indicated that vegetation and the water index significantly influence people's subjective responses to outdoor thermal environments [70,90], and that vegetation has a positive effect on perceived thermal comfort [72–74]. Increasing the area of water index can effectively reduce the temperature, and the combination with vegetation can provide a better cooling effect [91]. People prefer spaces where water is present [92]. Thermal comfort is associated with the naturalness of the environment, beauty, and positive experience [34,67,68]. People's overall comfort is higher in aesthetically pleasing environments [47]. Beautiful outdoor spaces are favored by residents and have a positive effect on enhancing thermal comfort [18]. Thermal tolerance is higher in humans in quiet and beautiful outdoor environments [11]. Sunlight perception and preference affect thermal perception [17]. Increased sunlight perception increases the proportion of people who feel hot outdoors [66]. These are all consistent with our conclusions.

In addition, the beauty of the scenic view is also influenced by color perception. It has been shown that emotions are associated with subjective thermal sensations [75,76], that good color design may lead to positive emotions, which may positively affect thermal perception [79], and that emotions mediate the effects of landscape elements on thermal comfort [77]. This is consistent with our study that changes in visual physical characteristics affect color perception, which acts as a mediator that significantly affects L, SO, and SV, ultimately leading to changes in thermal perception (Equations (8)–(11)), suggesting that color variations affect the perception of space and that rich color variations can increase spatial richness, thereby creating a more comfortable thermal environment.

5.1.3. Visual Design Strategies to Enhance Thermal Perception of Greenways

Enhancing the green visual index and optimizing the sky view index enhances the thermal perception of greenways. Studies have shown that GVI is negatively correlated with L. When designing greenways, consideration should be given to increasing the coverage of green vegetation, such as planting more trees and shrubs to provide shade and visual comfort. Appropriate adjustments to SVI can be made by designing tree canopies with different densities to reduce direct sunlight and diffuse light, thus creating a more comfortable visual environment.

Improving the sense of spatial enclosure and introducing water elements also enhances the thermal perception of greenways. The design should consider using landscape elements, such as hedges or low walls, to moderately enclose the space to enhance people's sense of security and thermal sensation. Enhanced SE enhances PR, moderately reduces SO and L, and is conducive to promoting TS and TP. Meanwhile, water characteristics such as streams, fountains, or artificial lakes can be introduced into the greenway design to enhance the visual environment's scenic view and thermal sensation.

Enhancing the degree of scenic view and enriching the environment with color can also enhance the thermal perception of greenways. The SV and TS of the greenways can be enhanced by increasing PR and C. The design can consider using plants of different colors and textures, choosing appropriate paving materials, improving the impact of large-area paving on the color of the space, and promoting the richness of the visual environment to enhance the degree of beauty, thus enhancing the degree of user enjoyment.

5.2. Limitations and Prospects of the Study

This study has some limitations in terms of spatial types. Greenways are linear spaces, and the main components of their visual characterization elements differ somewhat from other space types [90]. Paving index has an effect on thermal perception [47], and PI was only significantly correlated with C in this study, which may be due to the fact that the materials and widths of roads are similar in greenway environments, resulting in no significant difference in perception [65]. There are also differences in visual landscape characteristics across climate zones, and these factors may have different results on visual perception and thermal perception [41,42]. In this paper, climatic factors were controlled for, and picture stimuli were used instead of visual experiences in the field, which may have led to the influence of the spatial environment in which the respondents were located on visual perception and thermal perception. In the future, the mechanism of visual–thermal perception influence can be explored in depth in different types of spaces. Attempts were made to design controlled experiments to further validate and control individual differences in objective environmental parameters and physiological indices, which were analyzed together with the results of subjective questionnaires in order to assess the independent influence of visual characteristics on thermal perception.

Existing studies have shown that demographic characteristics, individual experience, and cultural background affect thermal perception [93]. The subjects were mostly residents of the Fujian area with no significant differences in thermal experience and cultural background, which made demographic characteristics and individual experience have no significant effect in this study, which is inconsistent with the results of previous studies [37–39]. There were significant differences in thermal sensation scores by gender in this study, but the results of group modeling were consistent with the overall model, which was stable across genders. This may be due to the fact that the respondents had similar thermal experiences as well as cultural backgrounds, and in this particular case demographic factors were not significant influences on the psychological modulation of thermal perception by vision. The group with higher salary levels had higher thermal sensation than the group with lower salary levels, which is consistent with previous findings [47,48]. Meanwhile, in outdoor spaces, activity time [45], and landscape sequence changes and combinations, affect transient thermal perception, which in turn affects individuals' overall satisfaction with outdoor spaces [74].

In the future, a combination of online and field survey methods could be used to increase participant diversity and explore differences in the effects of visual characteristics on thermal perception across different populations, such as those of different ages, genders, quality of life, and cultural backgrounds. The test period could also be expanded to assess how people adapt to the urban thermal environment over time and how this adaptation affects their perception of visual characteristics and thermal sensations. To further understand the issues of enhancing the thermal and visual environments of greenway spaces, a more comprehensive data collection and modeling approach is needed to incorporate other influencing factors into the model and to conduct studies in multiple cities to validate the general applicability of the model to create better outdoor thermal and visual environments.

6. Conclusions

The results of this study show that visual characteristics significantly affect thermal perception from both physical and perceptual levels; SE, WI, SV, and L are important influencing factors for TS. Increasing water index, spatial enclosure, and creating beautiful environments, as well as decreasing people's perception of light, can improve the thermal comfort of outdoor walking spaces; WI, SV, and TS have a positive effect on people's spatial preference, which suggests that spaces with water elements, beautiful environments, and cool thermal sensations are more favored by users.

In this study, we used the picture comparison method to quantify the effect of visual perceptual characteristics on thermal perception and combined it with computer vision technology to quantify visual physical characteristics, linking physical space and perception. Our study broadens the psychological pathway for thermal environment improvement in urban green space and provides scientific theoretical guidance for visual environment design of greenways in hot and humid areas. Although the model constructed in this study is based on Fuzhou, the method proposed in this paper is generalizable and applicable to the assessment of the visual thermal environment of urban walking spaces in other hot and humid areas. The results of this study have practical significance for urban landscape enhancement, and designers can use these findings to optimize the visual characteristics, predict the possible thermal perception situation of the design through visual evaluation during the design process, and adjust and optimize the design scheme in time. At the same time, the thermal comfort of the greenway space is regularly monitored and evaluated to ensure the effectiveness of the design, and adjustments are made based on user feedback to promote the use and enjoyment of urban green space and improve the quality of life of urban residents.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13111796/s1, Table S1. Data for modeling; Table S2. Questionnaire data summary; Table S3. Semantic segmentation of raw data; Table S4. Visual Characteristics, thermal environmental data.

Author Contributions: Conceptualization, validation, formal analysis, data curation, writing—original draft preparation, Y.Z.; methodology, Y.Z. and C.L.; software, Y.Z. and Y.L.; investigation, Y.Z., J.Z., S.H. and Y.L.; resources, S.L. and C.L.; visualization, Y.Z. and J.Z.; supervision, S.L. and C.L.; funding acquisition, writing—review and editing, C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Social Science Planning Project of Fujian Province, China: Research on Computer Vision-based Evaluation Method of Urban Greenway Running-supportive Quality (No. FJ2021C069), the National Natural Science Foundation of China: Research on Key Issues of Horticultural Therapy Program Formulation for College Students in the Early Warning of Psychological Crisis (No. 32301661), and General Project of Educational Research Program for Young and Middle-Aged Teachers in Fujian Province: Research on Spatial Characterization of Substances Associated with Restorative Qualities of Roadway Landscapes on University Campuses (No. JAS21067).

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Materials. Further inquiries can be directed to the corresponding author.

Acknowledgments: We are grateful to the 700 subjects who participated in the questionnaire survey, which obtained informed consent from all subjects. We also thank Youlong Sun and many other Master of Landscape Architecture students for their assistance in data collection, as well as Weicong Fu for equipment support in thermal environment measurements.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A.

Appendix A.1. The Specifications of the Tools Used

Table A1. The specifications of the tools used.

Microclimate Parameters	Measuring Tools	Measurement Range	Accuracy	Resolution	Response Time
Temperature (Ta)	Kestrel 5500 Handheld Weather Meter	−29 °C–70 °C	0.5 °C	0.1 °C	1 s
Wind speed (Va)		0.6–60 m/s	±3%	0.1 m/s	1 s
Humidity (RH)		5.0–95.0%	±2%	0.1	60 s
Solar radiation (G)	TES-1333 Solar Power Meter	0 to 1999 W/m^2	±10 W/m^2	0.1 W/m^2	1 s

Appendix A.2. Weather Conditions during the Survey

Table A2. Weather conditions during the survey.

Date	Temperature Range (°C)	Weather	Wind Force
6 July 2023	28–38	Cloudy	Level 2
7 July 2023	28–38	Cloudy	Level 2
8 July 2023	28–40	Sunny	Level 2
9 July 2023	28–40	Cloudy–Sunny	Level 1
10 July 2023	28–38	Cloudy–Sunny	Level 2
11 July 2023	27–38	Cloudy–Sunny	Level 2
12 July 2023	27–38	Cloudy	Level 2
13 July 2023	26–38	Cloudy	Level 2

Appendix A.3. Measured Thermal Environment Parameters of the Greenways

Table A3. Measured thermal environment parameters of the greenways.

	Ta (°C)			RH (%)			Va (m/s)			G (W/m²)		
Site	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
A	32.5	31.6	33.8	75.1	71.3	77.0	0.4	0	0.9	196	27.8	368.7
B	31.1	29.9	33.0	77.8	49.9	82.7	0.1	0	0.6	174.7	49.3	728.2
C	33.4	32.2	35.3	69.4	65.7	72.4	0.5	0	1.2	222.5	25.3	693.4
D	33.2	30.9	35.2	70.7	61.9	78.0	0.4	0	0.7	292.3	136.1	598.7
E	34.5	32.9	35.8	67.9	63.6	72.2	0.4	0	1.1	410.6	49.7	811.8

Table A3. *Cont.*

	Ta (°C)			RH (%)			Va (m/s)			G (W/m²)		
Site	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
F	32.5	31.1	33.7	74.9	70.5	78.20	0.2	0	1.1	178.0	25.6	719.4
G	35.4	34.8	36.2	64.2	61.4	67.9	0.4	0	1.0	379.4	25.3	885.3
H	33.7	32.9	35.0	72.8	67.7	75.6	0.3	0	0.7	266.1	104.9	580.3

Appendix A.4. Element of Visual Physical Characteristics

Table A4. Elements of visual physical characteristics.

	Percentage of Elements (*n* = 101)							
Tab	**A (*n* = 11)**	**B (*n* = 15)**	**C (*n* = 12)**	**D (*n* = 12)**	**E (*n* = 14)**	**F (*n* = 15)**	**G (*n* = 14)**	**H (*n* = 8)**
sky	27.95%	18.86%	13.96%	16.99%	21.08%	9.08%	22.26%	18.60%
tree	40.70%	37.11%	47.70%	36.79%	37.83%	47.49%	42.79%	41.49%
road	0.20%	3.02%	15.17%	1.20%	15.26%	4.26%	5.48%	6.37%
grass	0.35%	2.73%	13.67%	6.47%	3.12%	6.40%	12.70%	6.49%
sidewalk	3.03%	0.98%	2.31%	10.75%	2.69%	3.33%	7.35%	4.35%
earth	1.10%s	1.55%	1.13%	1.41%	1.72%	6.41%	0.98%	2.04%
plant	10.60%	4.79%	3.21%	17.41%	9.83%	10.26%	5.06%	8.73%
water	8.49%	0.09%	0.24%	0.02%	0.30%	0.37%	0.20%	1.39%
fence	2.31%	17.41%	0.56%	1.30%	5.65%	2.99%	1.12%	4.48%
railing	1.51%	2.67%	0.03%	0.34%	0.69%	0.08%	0.14%	0.78%
path	3.21%	7.24%	0.34%	5.53%	0.94%	8.03%	0.80%	3.73%
streetlight	0.33%	0.04%	0.48%	0.24%	0.33%	0.66%	0.64%	0.39%

Appendix B.

Appendix B.1. Visual Physical Characteristics Statistics

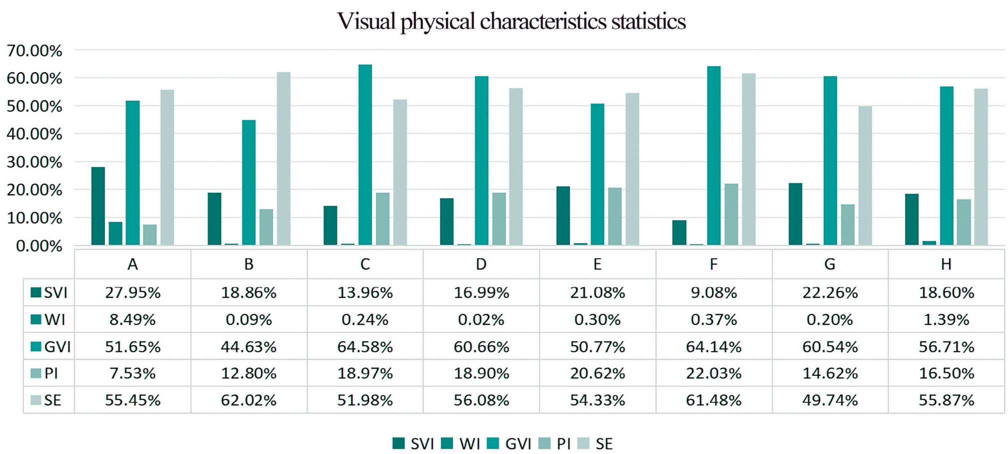


Figure A1. Visual physical characteristics statistics.

Appendix B.2. Visual Perception and Thermal Perception Statistics

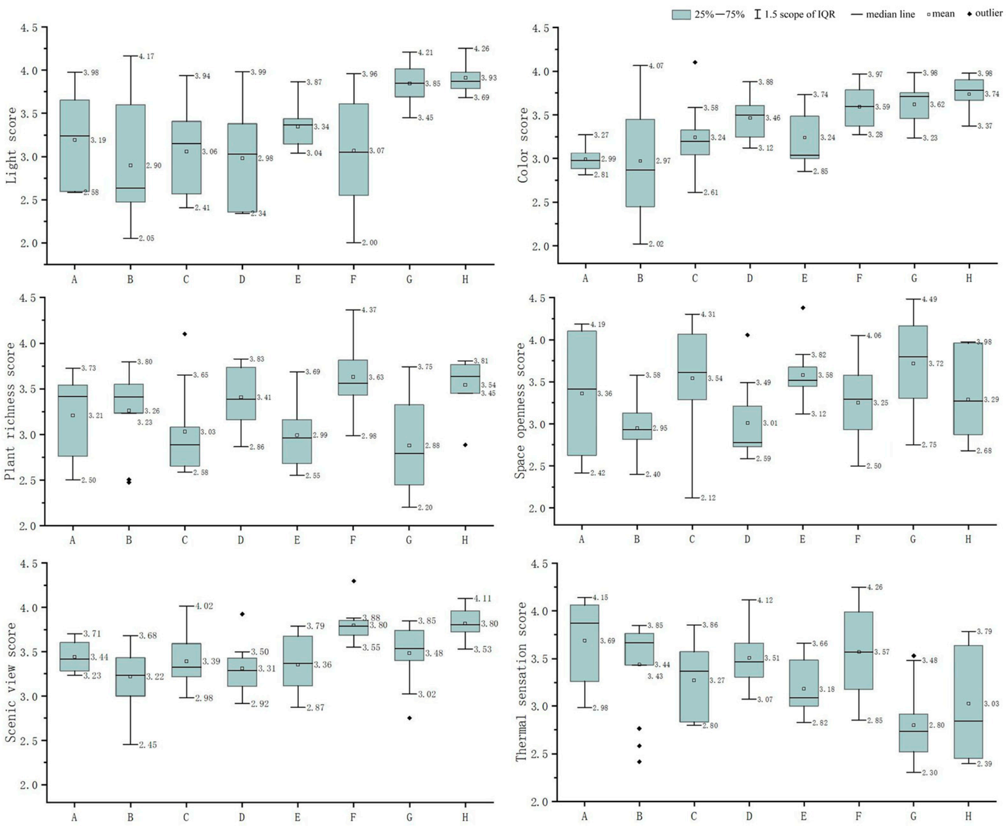


Figure A2. Visual perception and thermal perception statistics.

Appendix B.3. Normal Distribution of Visual Characteristics and Thermal Perception Indicators

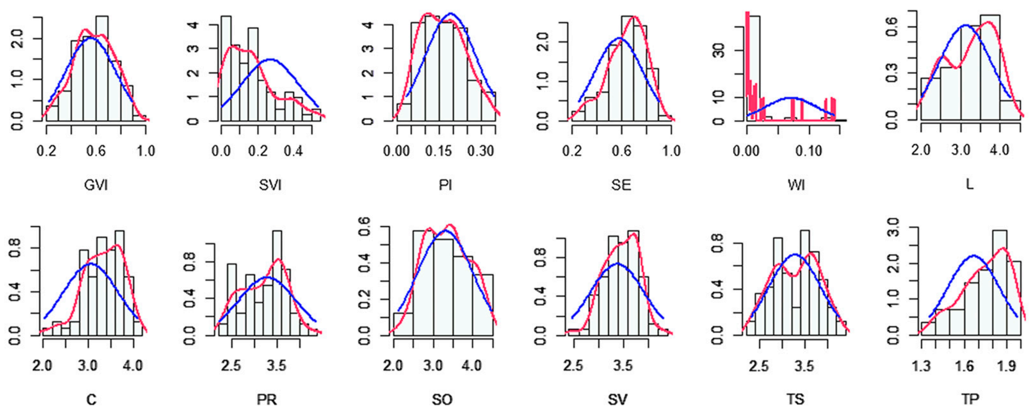


Figure A3. Normal distribution of visual characteristics and thermal perception indicators (the blue line represents the standard normal curve, and the red line represents the skewed curve).

Appendix C.

Questionnaire on the Effect of Greenways' Visual Characteristics on Thermal Perception

https://www.wjx.cn/vm/YDyYRvJ.aspx#, (accessed on 23 August 2024), https://www.wjx.cn/vm/e6LY89y.aspx#, (accessed on 23 August 2024)

https://www.wjx.cn/vm/YDheVYR.aspx#, (accessed on 23 August 2024), https://www.wjx.cn/vm/OdQUJVw.aspx#, (accessed on 23 August 2024)

https://www.wjx.cn/vm/wqDqrTs.aspx#, (accessed on 23 August 2024), https://www.wjx.cn/vm/OCkyQUJ.aspx#, (accessed on 23 August 2024)

https://www.wjx.cn/vm/QuO9f02.aspx#, (accessed on 23 August 2024), https://www.wjx.cn/vm/PaBCtvm.aspx#, (accessed on 23 August 2024)
https://www.wjx.cn/vm/PpCAPmB.aspx#, (accessed on 23 August 2024), https://www.wjx.cn/vm/rKweVgq.aspx#, (accessed on 23 August 2024)

References

1. Chen, L.; Ng, E. Outdoor Thermal Comfort and Outdoor Activities: A Review of Research in the Past Decade. *Cities* **2012**, *29*, 118–125. [CrossRef]
2. Zhang, T.; Huang, R.; Yang, M.; Lin, G.; Ma, X.; Wang, X.; Huang, Q. Perceptions of the Health Risk from Hot Days and the Cooling Effect of Urban Green Spaces: A Case Study in Xi'an, China. *Front. Public Health* **2023**, *11*, 1211164. [CrossRef] [PubMed]
3. Burrows, E.; O'Mahony, M.; Geraghty, D. How Urban Parks Offer Opportunities for Physical Activity in Dublin, Ireland. *Int. J. Environ. Res. Public Health* **2018**, *15*, 815. [CrossRef] [PubMed]
4. Lee, Y.-C.; Kim, K.-H. Attitudes of Citizens towards Urban Parks and Green Spaces for Urban Sustainability: The Case of Gyeongsan City, Republic of Korea. *Sustainability* **2015**, *7*, 8240–8254. [CrossRef]
5. Zhang, L.; Wei, D.; Hou, Y.; Du, J.; Liu, Z.; Zhang, G.; Shi, L. Outdoor Thermal Comfort of Urban Park-A Case Study. *Sustainability* **2020**, *12*, 1961. [CrossRef]
6. Yang, J.; Zhao, Y.; Zou, Y.; Xia, D.; Lou, S.; Guo, T.; Zhong, Z. Improving the Thermal Comfort of an Open Space via Landscape Design: A Case Study in Hot and Humid Areas. *Atmosphere* **2022**, *13*, 1604. [CrossRef]
7. Wang, W.; Li, Y.; Li, L.; Wang, R.; Wang, Y. Study on Thermal Comfort of Elderly in Community Parks: An Exploration from the Perspectives of Different Activities and Ages. *Build. Environ.* **2023**, *246*, 111001. [CrossRef]
8. Liu, Y.; Fan, J.; Xie, S.; Chen, X. Study on the Spatial and Temporal Distribution of Thermal Comfort and Its Influencing Factors in Urban Parks. *Atmosphere* **2024**, *15*, 183. [CrossRef]
9. Perini, K.; Chokhachian, A.; Dong, S.; Auer, T. Modeling and Simulating Urban Outdoor Comfort: Coupling ENVI-Met and TRNSYS by Grasshopper. *Energy Build.* **2017**, *152*, 373–384. [CrossRef]
10. Wong, N.H.; He, Y.; Ngoc, S.N.; Raghavan, S.; Martin, M.; Hii, D.J.C.; Yu, Z.; Deng, J. An Integrated Multiscale Urban Microclimate Model for the Urban Thermal Environment. *Urban Clim.* **2021**, *35*, 100730. [CrossRef]
11. Lau, K.K.-L.; Choi, C.Y. The Influence of Perceived Aesthetic and Acoustic Quality on Outdoor Thermal Comfort in Urban Environment. *Build. Environ.* **2021**, *206*, 108333. [CrossRef]
12. Chen, H.; Hong, B.; Qu, H.; Geng, Y.; Su, M. Effects of Acoustic Perception on Outdoor Thermal Comfort in Campus Open Spaces in China's Cold Region. *Buildings* **2022**, *12*, 1518. [CrossRef]
13. Chang, J.; Du, M.; Hong, B.; Qu, H.; Chen, H. Effects of Thermal-Olfactory Interactions on Emotional Changes in Urban Outdoor Environments. *Build. Environ.* **2023**, *232*, 110049. [CrossRef]
14. Shafavi, N.S.; Zomorodian, Z.S.; Tahsildoost, M.; Javadi, M. Occupants Visual Comfort Assessments: A Review of Field Studies and Lab Experiments. *Sol. Energy* **2020**, *208*, 249–274. [CrossRef]
15. Tan, Z.; Chung, S.C.; Roberts, A.C.; Lau, K.K.-L. Design for Climate Resilience: Influence of Environmental Conditions on Thermal Sensation in Subtropical High-Density Cities. *Archit. Sci. Rev.* **2019**, *62*, 3–13. [CrossRef]
16. Mayes, H.S.; Navarro, M.; Satchell, L.P.; Tipton, M.J.; Ando, S.; Costello, J.T. The Effects of Manipulating the Visual Environment on Thermal Perception: A Structured Narrative Review. *J. Therm. Biol.* **2023**, *112*, 103488. [CrossRef]
17. Lam, C.K.C.; Yang, H.; Yang, X.; Liu, J.; Ou, C.; Cui, S.; Kong, X.; Hang, J. Cross-Modal Effects of Thermal and Visual Conditions on Outdoor Thermal and Visual Comfort Perception. *Build. Environ.* **2020**, *186*, 107297. [CrossRef]
18. Manavvi, S.; Rajasekar, E. Assessing Thermal Comfort in Urban Squares in Humid Subtropical Climate: A Structural Equation Modelling Approach. *Build. Environ.* **2023**, *229*, 109931. [CrossRef]
19. Zhang, T.; Hong, B.; Su, X.; Li, Y.; Song, L. Effects of Tree Seasonal Characteristics on Thermal-Visual Perception and Thermal Comfort. *Build. Environ.* **2022**, *212*, 108793. [CrossRef]
20. Suzuki, T. *Photo Science Biology Catalogue*, 3rd ed.; Suken Publishing: Tokyo, Japan, 2014.
21. Wang, S.; Zhu, S. Neural Mechanism of Visual Information Processing. *Chin. Ophthalmic Res.* **2008**, *26*, 717–720.
22. Arnheim, R. *Visual Thinking: Thinking*, 2nd ed.; University of California Press: Berkeley, CA, USA, 2004.
23. Seung, H.S.; Lee, D.D. The Manifold Ways of Perception. *Science* **2000**, *290*, 2268–2269. [CrossRef]
24. Redies, C. Combining Universal Beauty and Cultural Context in a Unifying Model of Visual Aesthetic Experience. *Front. Hum. Neurosci.* **2015**, *9*, 218. [CrossRef] [PubMed]
25. Silvia, P.J. Confusion and Interest: The Role of Knowledge Emotions in Aesthetic Experience. *Psychol. Aesthet. Creat. Arts* **2010**, *4*, 75–80. [CrossRef]
26. Liu, J.; Wei, Y.; Lu, S.; Wang, R.; Chen, L.; Xu, F. The Elderly's Preference for the Outdoor Environment in Fragrant Hills Nursing Home, Beijing: Interpreting the Visual-Behavioural Relationship. *Urban For. Urban Green.* **2021**, *64*, 127242. [CrossRef]
27. Tabatabaie, S.; Litt, J.S.; Muller, B.H.F. Sidewalks, Trees and Shade Matter: A Visual Landscape Assessment Approach to Understanding People's Preferences for Walking. *Urban For. Urban Green.* **2023**, *84*, 127931. [CrossRef]
28. Li, J.; Huang, Z.; Zhu, Z.; Ding, G. Coexistence Perspectives: Exploring the Impact of Landscape Features on Aesthetic and Recreational Values in Urban Parks. *Ecol. Indic.* **2024**, *162*, 112043. [CrossRef]

29. Johansson, E.; Thorsson, S.; Emmanuel, R.; Krüger, E. Instruments and Methods in Outdoor Thermal Comfort Studies—The Need for Standardization. *Urban Clim.* **2014**, *10*, 346–366. [CrossRef]
30. *ISSN 1041-2336-ANSI*; American Society of Heating, Refrigerating, and Air-Conditioning Engineers Standard. ASHRAE Standard: Peachtree Corners, GA, USA, 2021.
31. Schweiker, M.; Schakib-Ekbatan, K.; Fuchs, X.; Becker, S. A Seasonal Approach to Alliesthesia. Is There a Conflict with Thermal Adaptation? *Energy Build.* **2020**, *212*, 109745. [CrossRef]
32. Rohles, F.H., Jr. Thermal Comfort and Strategies for Energy Conservation. *J. Soc. Issues* **1981**, *37*, 132–149. [CrossRef]
33. Lai, D.; Lian, Z.; Liu, W.; Guo, C.; Liu, W.; Liu, K.; Chen, Q. A Comprehensive Review of Thermal Comfort Studies in Urban Open Spaces. *Sci. Total Environ.* **2020**, *742*, 140092. [CrossRef]
34. Nikolopoulou, M.; Steemers, K. Thermal Comfort and Psychological Adaptation as a Guide for Designing Urban Spaces. *Energy Build.* **2003**, *35*, 95–101. [CrossRef]
35. Shooshtarian, S.; Rajagopalan, P. Study of Thermal Satisfaction in an Australian Educational Precinct. *Build. Environ.* **2017**, *123*, 119–132. [CrossRef]
36. Peng, Y.; Feng, T.; Timmermans, H.J.P. Heterogeneity in Outdoor Comfort Assessment in Urban Public Spaces. *Sci. Total Environ.* **2021**, *790*, 147941. [CrossRef] [PubMed]
37. Lam, C.K.C.; Hang, J.; Zhang, D.; Wang, Q.; Ren, M.; Huang, C. Effects of Short-Term Physiological and Psychological Adaptation on Summer Thermal Comfort of Outdoor Exercising People in China. *Build. Environ.* **2021**, *198*, 107877. [CrossRef]
38. Xie, Y.; Wang, X.; Wen, J.; Geng, Y.; Yan, L.; Liu, S.; Zhang, D.; Lin, B. Experimental Study and Theoretical Discussion of Dynamic Outdoor Thermal Comfort in Walking Spaces: Effect of Short-Term Thermal History. *Build. Environ.* **2022**, *216*, 109039. [CrossRef]
39. Lam, C.K.C.; Gao, Y.; Yang, H.; Chen, T.; Zhang, Y.; Ou, C.; Hang, J. Interactive Effect between Long-Term and Short-Term Thermal History on Outdoor Thermal Comfort: Comparison between Guangzhou, Zhuhai and Melbourne. *Sci. Total Environ.* **2021**, *760*, 144141. [CrossRef]
40. Naheed, S.; Shooshtarian, S. A Review of Cultural Background and Thermal Perceptions in Urban Environments. *Sustainability* **2021**, *13*, 9080. [CrossRef]
41. Brychkov, D.; Garb, Y.; Pearlmutter, D. The Influence of Climatocultural Background on Outdoor Thermal Perception. *Int. J. Biometeorol.* **2018**, *62*, 1873–1886. [CrossRef]
42. Aljawabra, F.; Nikolopoulou, M. Thermal Comfort in Urban Spaces: A Cross-Cultural Study in the Hot Arid Climate. *Int. J. Biometeorol.* **2018**, *62*, 1901–1909. [CrossRef]
43. Lyu, K.; Brambilla, A.; Globa, A.; de Dear, R. A Socio-Cultural Perspective to Semi-Outdoor Thermal Experience and Restorative Benefits-Comparison between Chinese and Australian Cultural Groups. *Build. Environ.* **2023**, *243*, 110622. [CrossRef]
44. Zhou, Z.; Jiao, R.; Dong, L. The Influence of Perceived Control on Outdoor Thermal Comfort: A Case Study in a Hot Summer and Warm Winter Climate. *Build. Environ.* **2023**, *245*, 110872. [CrossRef]
45. Krueger, E.L.; Tamura, C.A.; Broede, P.; Schweiker, M.; Wagner, A. Short-and Long-Term Acclimatization in Outdoor Spaces: Exposure Time, Seasonal and Heatwave Adaptation Effects. *Build. Environ.* **2017**, *116*, 17–29. [CrossRef]
46. Manavvi, S.; Rajasekar, E. Evaluating Outdoor Thermal Comfort in "Haats"—The Open Air Markets in a Humid Subtropical Region. *Build. Environ.* **2021**, *190*, 107527. [CrossRef]
47. Lenzholzer, S.; Klemm, W.; Vasilikou, C. Qualitative Methods to Explore Thermo-Spatial Perception in Outdoor Urban Spaces. *Urban Clim.* **2018**, *23*, 231–249. [CrossRef]
48. He, X.; An, L.; Hong, B.; Huang, B.; Cui, X. Cross-Cultural Differences in Thermal Comfort in Campus Open Spaces: A Longitudinal Field Survey in China's Cold Region. *Build. Environ.* **2020**, *172*, 106739. [CrossRef]
49. Singh, M.K.; Ooka, R.; Rijal, H.B.; Kumar, S.; de Dear, R. Adaptive Thermal Comfort in the Offices of Three Climates of North-East India. *J. Build. Eng.* **2023**, *75*, 106843. [CrossRef]
50. Déjeant-Pons, M. The European Landscape Convention. *Landsc. Res.* **2006**, *31*, 363–384. [CrossRef]
51. Knez, I.; Thorsson, S.; Eliasson, I.; Lindberg, F. Psychological Mechanisms in Outdoor Place and Weather Assessment: Towards a Conceptual Model. *Int. J. Biometeorol.* **2009**, *53*, 101–111. [CrossRef]
52. Berson, D.M.; Dunn, F.A.; Takao, M. Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock. *Science* **2002**, *295*, 1070–1073. [CrossRef]
53. Vigier, T.; Moreau, G.; Siret, D. From Visual Cues to Climate Perception in Virtual Urban Environments. In Proceedings of the 2015 IEEE Virtual Reality (VR), Arles, France, 23–27 March 2015; pp. 305–306.
54. Xu, A.J.; Labroo, A.A. Incandescent Affect: Turning on the Hot Emotional System with Bright Light. *J. Consum. Psychol.* **2014**, *24*, 207–216. [CrossRef]
55. Lenzholzer, S.; de Vries, S. Exploring Outdoor Thermal Perception-a Revised Model. *Int. J. Biometeorol.* **2020**, *64*, 293–300. [CrossRef] [PubMed]
56. Lutterschmidt, D.I.; Lutterschmidt, W.I.; Hutchison, V.H. Melatonin and Thermoregulation in Ectothermic Vertebrates: A Review. *Can. J. Zool.* **2003**, *81*, 1–13. [CrossRef]
57. Egan, G.F.; Johnson, J.; Farrell, M.; McAllen, R.; Zamarripa, F.; McKinley, M.J.; Lancaster, J.; Denton, D.; Fox, P.T. Cortical, Thalamic, and Hypothalamic Responses to Cooling and Warming the Skin in Awake Humans: A Positron-Emission Tomography Study. *Proc. Natl. Acad. Sci. USA* **2005**, *102*, 5262–5267. [CrossRef] [PubMed]

58. Muzik, O.; Diwadkar, V.A. Depth and Hierarchies in the Predictive Brain: From Reaction to Action. *Wiley Interdiscip. Rev.-Cogn. Sci.* **2023**, *14*, e1664. [CrossRef]
59. Teoh, M.-Y.; Shinozaki, M.; Said, I. Redefining the Notion of Outdoor Thermal Comfort. *SEATUC J. Sci. Eng.* **2020**, *1*, 52–61.
60. Bennett, C.A.; Rey, P. What's So Hot about Red? *Hum. Factors* **1972**, *14*, 149–154. [CrossRef]
61. Ho, H.-N.; Van Doorn, G.H.; Kawabe, T.; Watanabe, J.; Spence, C. Colour-Temperature Correspondences: When Reactions to Thermal Stimuli Are Influenced by Colour. *PLoS ONE* **2014**, *9*, e91854. [CrossRef]
62. Ziat, M.; Balcer, C.A.; Shirtz, A.; Rolison, T. A Century Later, The Hue-Heat Hypothesis: Does Color Truly Affect Temperature Perception? In *Haptics: Perception, Devices, Control, and Applications*; Bello, F., Kajimoto, H., Visell, Y., Eds.; Springer: Cham, Switzerland, 2016; Volume 9774, pp. 273–280.
63. Hettiarachchi, A.; Emmanuel, R. Colour as a Psychological Agent to Manipulate Perceived Indoor Thermal Environment for Low Energy Design; Cases Implemented in Sri Lanka. In Proceedings of the Passive Low Energy Architecture (PLEA) 2017—Design to Thrive, Edinburgh, UK, 2–5 July 2017.
64. Ou, L.C.; Luo, M.R.; Woodcock, A.; Wright, A. A Study of Colour Emotion and Colour Preference. Part I: Colour Emotions for Single Colours. *Color Res. Appl.* **2004**, *29*, 232–240. [CrossRef]
65. Lenzholzer, S.; van der Wulp, N.Y. Thermal Experience and Perception of the Built Environment in Dutch Urban Squares. *J. Urban Des.* **2010**, *15*, 375–401. [CrossRef]
66. Ning, S.; Jing, W.; Ge, Z. Sunlight Perception and Outdoor Thermal Comfort in College Campuses: A New Perspective. *Sci. Rep.* **2023**, *13*, 16112. [CrossRef]
67. Eliasson, I.; Knez, I.; Westerberg, U.; Thorsson, S.; Lindberg, F. Climate and Behaviour in a Nordic City. *Landsc. Urban Plan.* **2007**, *82*, 72–84. [CrossRef]
68. Nikolopoulou, M. Outdoor Thermal Comfort. *Front. Biosci.* **2011**, *S3*, 1552. [CrossRef] [PubMed]
69. Mohammadzadeh, N.; Karimi, A.; Brown, R.D. The Influence of Outdoor Thermal Comfort on Acoustic Comfort of Urban Parks Based on Plant Communities. *Build. Environ.* **2023**, *228*, 109884. [CrossRef]
70. Xi, T.; Zhang, X.; Jin, W.; Xu, W.; Wu, Y.; Qin, H. Primary Exploration of Leisure Path Design along Songhua River by a Small Number of Sample Experiment, Considering Several Multiple Indexes. *Atmosphere* **2022**, *13*, 1165. [CrossRef]
71. Wang, X.; Chen, Z.; Ma, D.; Zhou, T.; Chen, J.; Jiang, X. Relationship between Visual and Thermal Comfort and Electrodermal Activity in Campus Blue–Green Spaces: A Case Study of Guangzhou, China. *Sustainability* **2023**, *15*, 11742. [CrossRef]
72. Klemm, W.; Heusinkveld, B.G.; Lenzholzer, S.; Jacobs, M.H.; Van Hove, B. Psychological and Physical Impact of Urban Green Spaces on Outdoor Thermal Comfort during Summertime in The Netherlands. *Build. Environ.* **2015**, *83*, 120–128. [CrossRef]
73. Sun, F.; Zhang, J.; Yang, R.; Liu, S.; Ma, J.; Lin, X.; Su, D.; Liu, K.; Cui, J. Study on Microclimate and Thermal Comfort in Small Urban Green Spaces in Tokyo, Japan—A Case Study of Chuo Ward. *Sustainability* **2023**, *15*, 16555. [CrossRef]
74. Peng, Z.; Bardhan, R.; Ellard, C.; Steemers, K. Urban Climate Walk: A Stop-and-Go Assessment of the Dynamic Thermal Sensation and Perception in Two Waterfront Districts in Rome, Italy. *Build. Environ.* **2022**, *221*, 109267. [CrossRef]
75. Thorsson, S.; Honjo, T.; Lindberg, F.; Eliasson, I.; Lim, E.-M. Thermal Comfort and Outdoor Activity in Japanese Urban Public Places. *Environ. Behav.* **2007**, *39*, 660–684. [CrossRef]
76. Kim, M.; Chong, S.C.; Chun, C.; Choi, Y. Effect of Thermal Sensation on Emotional Responses as Measured through Brain Waves. *Build. Environ.* **2017**, *118*, 32–39. [CrossRef]
77. Yan, T.; Jin, H.; Jin, Y. The Mediating Role of Emotion in the Effects of Landscape Elements on Thermal Comfort: A Laboratory Study. *Build. Environ.* **2023**, *233*, 110130. [CrossRef]
78. Wang, H.; Liu, L. Experimental Investigation about Effect of Emotion State on People's Thermal Comfort. *Energy Build.* **2020**, *211*, 109789. [CrossRef]
79. Wang, H.; Liu, G.; Hu, S.; Liu, C. Experimental Investigation about Thermal Effect of Colour on Thermal Sensation and Comfort. *Energy Build.* **2018**, *173*, 710–718. [CrossRef]
80. Lenzholzer, S.; Koh, J. Immersed in Microclimatic Space: Microclimate Experience and Perception of Spatial Configurations in Dutch Squares. *Landsc. Urban Plan.* **2010**, *95*, 1–15. [CrossRef]
81. Lehnert, M.; Geletič, J.; Kopp, J.; Brabec, M.; Jurek, M.; Pánek, J. Comparison between Mental Mapping and Land Surface Temperature in Two Czech Cities: A New Perspective on Indication of Locations Prone to Heat Stress. *Build. Environ.* **2021**, *203*, 108090. [CrossRef]
82. Rodiek, S.D.; Fried, J.T. Access to the Outdoors: Using Photographic Comparison to Assess Preferences of Assisted Living Residents. *Landsc. Urban Plan.* **2005**, *73*, 184–199. [CrossRef]
83. Cortesão, J.; Brandão Alves, F.; Raaphorst, K. Photographic Comparison: A Method for Qualitative Outdoor Thermal Perception Surveys. *Int. J. Biometeorol.* **2020**, *64*, 173–185. [CrossRef]
84. Xu, H.; Zhu, Y.H.; Zhen, T.; Li, Z.H. Survey of Image Semantic Segmentation Methods Based on Deep Neural Network. *J. Front. Comput. Sci. Technol.* **2021**, *15*, 47–59.
85. Geiger, D.; Pearl, J. Logical and Algorithmic Properties of Independence and Their Application to Bayesian Networks. *Ann. Math. Artif. Intell.* **1990**, *2*, 165–178. [CrossRef]
86. Lindell, M.K.; Brandt, C.J. Measuring Interrater Agreement for Ratings of a Single Target. *Appl. Psychol. Meas.* **1997**, *21*, 271–278. [CrossRef]
87. Chakraborty, B. Learning Bayesian Belief Networks: An Approach Based on the MDL Principle. *Comput. Intell.* **1994**, *10*, 269–293.

88. Doguc, O.; Ramirez-Marquez, J.E. A Generic Method for Estimating System Reliability Using Bayesian Networks. *Reliab. Eng. Syst. Saf.* **2009**, *94*, 542–550. [CrossRef]
89. Xu, J.-G.; Zhao, Y.; Chen, J.; Han, C. A Structure Learning Algorithm for Bayesian Network Using Prior Knowledge. *J. Comput. Sci. Technol.* **2015**, *30*, 713–724. [CrossRef]
90. Lee, Y.Y.; Md Din, M.F.; Iwao, K.; Lee, Y.H.; Anting, N. Impact of Thermal Behaviour of Different Environmental Conditions on Ambient Environment and Thermal Discomfort in Malaysia. *Indoor Built Environ.* **2021**, *30*, 520–534. [CrossRef]
91. Syafii, N.I.; Ichinose, M.; Wong, N.H.; Kumakura, E.; Jusuf, S.K.; Chigusa, K. Experimental Study on the Influence of Urban Water Body on Thermal Environment at Outdoor Scale Model. *Procedia Eng.* **2016**, *169*, 191–198. [CrossRef]
92. Luo, J.; Zhao, T.; Cao, L.; Biljecki, F. Water View Imagery: Perception and Evaluation of Urban Waterscapes Worldwide. *Ecol. Indic.* **2022**, *145*, 109615. [CrossRef]
93. Chen, X.; Xue, P.; Liu, L.; Gao, L.; Liu, J. Outdoor Thermal Comfort and Adaptation in Severe Cold Area: A Longitudinal Survey in Harbin, China. *Build. Environ.* **2018**, *148*, 548–560. [CrossRef]