THE SPATIAL ENVIRONMENT AFFECTS HUMAN EMOTION PERCEPTION-USING PHYSIOLOGICAL SIGNAL MODES

XINYUE DING[1], XIANGMIN GUO[2], TIANTIAN LO[3] and KE WANG[4]
[1,2,3] *Harbin Institute of Technology (Shenzhen),* [4]*Tongji University.*
[1] *xinyueding00@gmail.com*
[2] *24904404@qq.com*
[3] *skyduo@gmail.com, 0000-0002-1992-0777*
[4] *kew@tongji.edu.cn*

Abstract. In the past, spatial design was mainly from the perspective of designers. With the increasing demand for quality spaces, contemporary architecture has gradually shifted from focusing on form creation to human well-being, once again advocating the concept of "human-centered" spatial design. Exploring how the spatial environment affects human emotions and health is conducive to quantifying the emotional perception characteristics of space and promoting the improvement of human quality of life and sustainable survival. At the same time, the development of contemporary technology and neuroscience has promoted the study of the impact of spatial environment on human emotion perception. This paper summarizes the research on the impact of the spatial environment on human emotion perception in recent years. First, 28 relevant studies were screened using the PRISMA framework. Then a set of research processes applicable to this study is proposed. Next, the physiological signals currently used to study the effects of the spatial environment on human emotions are summarized and analyzed, including electroencephalography (EEG), skin response (GSR), pulse (PR), and four other signals. The architectural features studied in the related literature are mainly building structural features, building spatial geometric features, and building spatial functional attributes. The study of urban space is divided into different parts, such as urban environment characteristics and urban wayfinding behavior. Finally, we point out the shortcomings and perspectives of studies related to the influence of spatial environment on human emotion perception.

Keywords. Architectural Space Environment; Urban Space; Human Emotional Feelings; Physiological Signals; SDG 11.

1. Introduction

With the continuous improvement of human material living standards, the concepts of liveable environment, sustainable development, and humanized design are gradually

POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2022, Volume 2, 425-434.

advocated by people. People's demand for architectural space is limited to functional requirements and puts forward new needs for the comfort and spirituality of the spatial environment. In order to meet the high quality requirements put forward by people for the spatial environment, the design thinking perspective of designers has changed from "usable" to "comfortable". Focusing on people's emotional perception of spatial environment characteristics has become an emerging research direction in spatial design at present, while promoting the enhancement of human life quality and the development of society in the direction of human-centeredness.

Traditionally, people's experiential feelings about space have been expressed mainly through language, such as oral narratives in the form of interviews, questionnaires to record feelings. However, these methods are highly subjective. People have been searching for ways to quantify the changes in people's emotions objectively.

In 1997, Rosalind W. Picard proposed that machines learn human emotions through scientific means: affective computing. Affective computing hopes that computers can recognize, understand and express human feelings (Picard, 1999), focusing mainly on the direction of human language, facial expressions, body gestures, and physiological signals. At the same time, the maturity and development of sensor device technology have facilitated the collection and analysis of human body modality data, making it possible to quantify people's feelings and emotions.

In recent years, with the development of artificial intelligence, affective computing has gradually become a hot topic in the development of science and technology. Numerous studies on psychology, behavior, architecture and other fields have attempted to redefine and explain the impact of the spatial environment on human emotional feelings by using affective computing technology. Effective computing techniques can quantify human emotions while observing the effects on the body that humans do not subjectively perceive. Among the many effective computing modalities, physiological signals are considered ideal for objectively quantifying human emotions because they most directly reflect the physiological changes when human emotions change. However, it is still challenging to explain the influence and relationship of the spatial environment on human emotional feelings. One establishes the correlation between human physiological data and human emotions; the second is how different spatial environments induce human emotions, i.e., the spatial environmental factors that influence human emotions.

This paper contributes to the conference SDG11 of sustainable cities and communities through discussing the current state of research on the effects of spatial environment on human emotion perception and summarizing the current state, limitations, and future trends in the use of physiological signalling technologies. The future development of cities and communities still follows the principle of "people-centered" development, and it is necessary to use human emotions as the entry point for research and design.

2. Methodology

2.1. DATA COLLECTION

This article searches the literature from 2010 to the present and focuses on using human physiological sensors to study the effects of the spatial environment on human emotional perception. Human physiological sensors can detect human physiological indicators such as heart rate, blood pressure, skin electrical activity, EEG. The spatial environment includes urban space and architectural space. The spatial form consists of the physical spatial environment, and the study of the virtual spatial environment is included in the search and analysis.

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) study to select the research literature. This included the following steps: literature search, primary literature screening, inclusion, and literature synthesis. In the literature search phase, first, we conducted a database literature search in web of science using pre-defined keywords, such as "architecture space," "physical space," "virtual space," and "emotion recognition," "sensors." After the initial literature screening, we screened a total of 197 articles. Other sources were 31 articles (Figure 1).

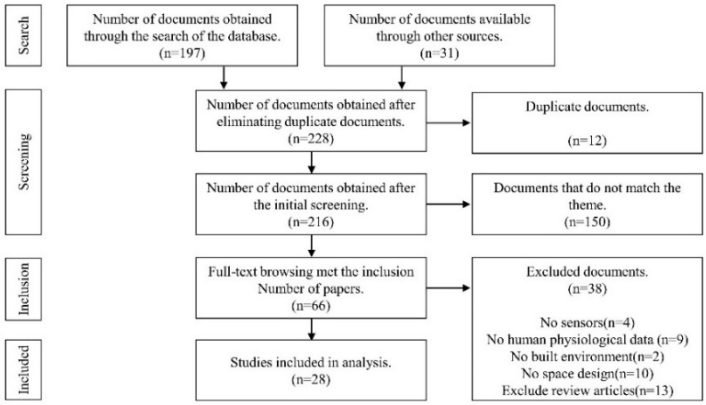


Figure 1. The review process using the PRISMA analysis framework

Next, we screened the retrieved literature, and the screening steps were.

(1) first, investigating and analyzing the titles to de-duplicate the 12 groups of duplicate literature.

(2) Then, by investigating the titles and abstracts, the literature that did not match the study of spatial characteristics of buildings as the object of study while using physiological signal sensors as the study approach was investigated for exclusion. A total of 150 records were excluded because they did not correspond to the study topic.

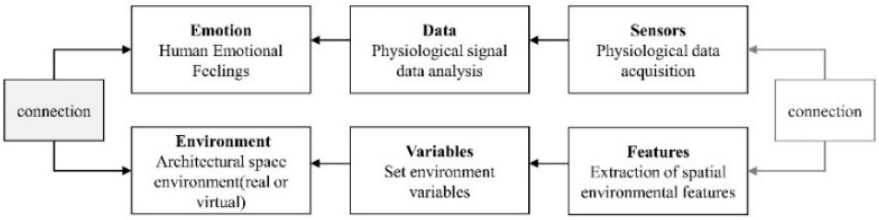
(3) Next, we conducted further in-depth research on these 66 records to filter out those that fit the research topic. We filtered our final range of research literature by the following filtering sequence: ①literature that used sensor technology as a research method was selected. Four studies were excluded because they did not use physiological sensors; ②the studies were conducted on human physiological data changes, with human physiological data as the primary influencing variable for the overall research. Nine studies were excluded because they did not use human

physiological sensor data as the data source; ③ the study environments were architectural or urban spatial environments. Both real and virtual environments were used as the scope of this review. Two of the studies were excluded because the environments were non-building or urban-related; ④ the literature should focus on the changing relationship between people's physiological data and the spatial environment, rather than on other unrelated areas such as mental illness treatment and product design. Ten studies were excluded because they were not related to spatial environment design; ⑤ relevant research literature was excluded from this study, and 13 articles were reviewed.

Twenty-eight studies were eventually included in the research analysis, and they used sensors to collect data on human physiological signals and, at the same time, to study the relationship between 3D spatial environments and human emotional feelings, from which they analyzed how architectural or urban spatial environments affect human emotions, thoughts, and behaviors. Figure 1 illustrates the process of deriving our final study database using the PRISMA framework.

3. Research Framework and Research questions

After conducting a literature search and screening, we will propose the following process applies to this study by analyzing and studying these screened 28 papers based on the research topic. Firstly, we will clarify the research content, and the research topic is the influence of spatial environment on human emotional feelings. Next, it should be defined which spatial environment features change human emotional feelings. The built spatial environment features are extracted as spatial environment variables for the analysis of the study. Then, regarding the quantification process of human experience feelings, physiological characteristics are converted into measurable physiological signal data by physiological signal sensors, and physiological data are converted into human emotions using relevant models. Finally, an attempt is made to obtain two associations through the above process, one between human emotion and spatial environmental features and the other between spatial environmental features and



human physiological signals. The whole research process is shown in Figure 2.

Figure 2. Research Framework

We ask the following questions based on the above research framework and analyze the association between the built spatial environment and human emotional feelings.

Question 1: What physiological signals have been used to study the relationship between spatial environments and human emotional feelings?

Question 2: Which built spatial environment features have been studied in the literature?

Question 3: Is it possible to obtain associations between built environment features and human physiological signals?

The above questions guide our findings. Question 1 is about the relationship between sensor devices and human physiological signals, and we list the relationship between human body modalities, physiological signals, and sensors. Question 2 is about architectural spatial environment characteristics, and we establish the relationship between architectural spatial elements and research methods and human emotions. Regarding question 3, we analyze the physiological signals against the architectural spatial features.

4. Results and discussion

4.1. HUMAN PHYSIOLOGICAL CHARACTERISTICS AND PHYSIOLOGICAL SIGNALS (QUESTION 1)

A total of 8 physiological characteristics were extracted from these 28 papers: EEG, skin electrical response, heart rate, blood pressure, pulse, eye movements, and facial expressions (Table 1).

Table 1. Human physiological characteristics and physiological signals in the literature

Category	Features	Sensors	Products	Number of References
Nerve Activity	Brain Waves	Electroencephalography(EEG)	Emotiv EPOC; NeuroSky	N=16
	Skin Electrical Value	Galvanic Skin Response (GSR); Electrodermal Activity(EDA)	Shimmer 3 GSR	N=8
Physiological Activities	Pulse Rate	Pulse Rate(PR)	near-infrared spectroscopy(NIRS)	N=1
	Blood Pressure	Blood Pressure(BP)	near-infrared spectroscopy(NIRS)	N=1
	Heart Rate	Heart Rate (HR)	Photoplethysmogram (PPG); Electrocardiogram (ECG)	N=6
Physical Activity	Gazing Point	Eye-tracking (ET)	Eye tracking cameras	N=4
	Facial Action Data	Facial Action Data	The iMotions software	N=1

EEG is the collection of brain nerve cell activity signals at the human cerebral cortex through EEG detection equipment, and then after extraction and processing, the EEG signal is divided into different human emotional states using the frequency domain of EEG frequency (Nunez et al., 1997; Shemesh et al., 2021). Skin electrical response is when human beings are subject to external stimuli or internal emotional fluctuations. It will cause changes in skin electrical conductivity by detecting human

skin resistance. You can have a preliminary judgment of people's emotions (Shemesh et al., 2021). Heart rate changes can reflect people's emotional state in different spatial environments. In contrast, signals such as blood pressure and pulse rate can collect the moments when people feel "excited" or "calm." (Tsunetsugu et al., 2005). Eye movements visually show people's attention in different spatial environments, and at the same time, according to people's eye movement signals also reflect human emotional changes (Sussman & Ward, 2019).

In Table 1, different physiological features and sensors affect human emotions in the spatial environment. Human physiological characteristics are classified as neural, physiological, and physical features, and various human physiological features have a strong connection with human emotions. The commonly used human physiological signals are EEG signals, skin electricity, heart rate, and eye movement data compared to other physiological features. The most frequently used physiological feature was EEG, with 16 studies using EEG as the primary human physiological feature, accounting for 57.14% of the total studies. This was followed by skin electrical, heart rate, and eye movements, accounting for 28.57%, 21.42%, and 14.28%, respectively.

Human emotional, perceptual responses to the spatial environment are potential and unconscious. The potential human reactions to different spatial environments can be observed concretely by detecting human physiological signals. Among many physiological features, EEG can directly observe the neural activity of the human cerebral cortex using sensors, which is the most direct indicator of human emotional changes among physiological signals and has a significant role in identifying human emotions.

4.2. SPATIAL ENVIRONMENT FEATURES (QUESTION 2)

In recent years, related scholars have studied the relationship between spatial environmental features and human emotions. Table 2 shows the analytical studies of using physiological signals for spatial features in different spatial scenes.

Among the spatial forms in related studies, realspace is mainly used in urban space research, and both real space and virtual space are used in architectural space experiments. The possible reasons for the less adoption of virtual space form in the research about the urban spatial environment are: 1) the 3D virtual model of urban space is not easy to obtain; 2) it is difficult to ensure that the virtual urban environment is entirely consistent with the real urban environment. At the same time, compared with the controllability of architectural space features, urban street space has stronger uncertainties.

Second, about relevant research characteristics. Research on urban space can be roughly divided into the following categories: 1) the influence of environmental features on human emotions in urban space, 2) emotional changes in human wayfinding behavior in urban environments, 3) the influence of building facades on human points of interest in cities, and 4) human spatial preferences in virtual urban environments. Research on architectural space can be broadly divided into the following categories: 1) functional properties of architectural space, which refers to the focus on office space, living space or others in the experiment; 2) physical environmental characteristics of architectural space, which refers to the focus on the

physical environment such as temperature and humidity in the space; 3) structural characteristics of architectural space, which refers to the focus on the structural elements of the space such as wooden elements; 4) geometric characteristics of architectural space, which refers to the focus on the geometric shape of the space such as rectangular or curved； 5) wayfinding behavior of architectural space, focusing on the change of people's emotional perception in the process of space wayfinding.

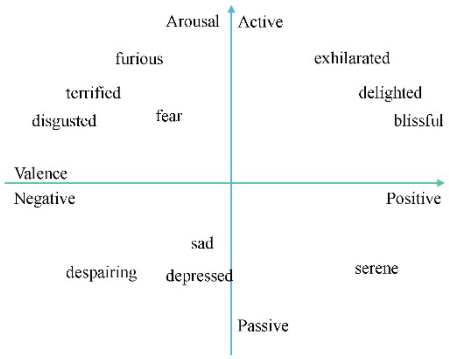
Research in urban space focuses on the influence of environmental features on human emotions. Research on architectural space includes structural characteristics, physical environmental characteristics of space, geometric characteristics of architectural space. Most studies focus on architectural interior spaces and are more diverse regarding research within architectural spaces.

Table 2. Different spatial scenarios are studied using physiological signals for the analysis of spatial features

Category	Form	Research Subjects	Emotion	Sensors	Reference
Urban Space (Outdoor Space)	Real Environment	Urban built environments	Valence	HR EEG ET GSR PPG	N=8
		Urban trails pathfinding behavior	Arousal	EEG	N=1
		Building elevation points of interest	Arousal	ET	N=1
	Virtual Environment	Environmental preference	Arousal	EDA HR	N=1
Architectural Space (Interior Space)	Real Environment	Nature of architectural space	Valence	EEG	N=2
		Features of the physical environment of the building space	Valence	GSR Facial Action Data	N=1
		Architectural space structure characteristics	Valence or Arousal	EEG PR BP ECG EDA rCBF	N=5
	Virtual Environment	Geometric features of space	Valence	EEG GSR ET	N=3
		Architectural space structure characteristics	Valence or Arousal	EDA EEG GSR PPG	N=3
		Spatial pathfinding behaviour	Valence	EEG	N=1

Third, about human emotions in research. The influence of spatial environment on human emotions is subtle, and humans may not realize the influence of space on their own emotions when they are in the environment. The use of physiological signal sensors can detect emotional changes that humans do not detect. Human emotion classification is mainly based on the VA emotion model proposed by Russell. Emotional dimensions are not independent but interconnected. He describes emotions through two dimensions: valence and arousal (Table 2). Valence indicates the degree

of perceived positivity or negativity to distinguish between positive or negative emotions; arousal indicates the degree of emotional calmness or arousal(Russell, 1980). The categorization of human emotions in most studies is based on valence, i.e., most studies have analyzed the positive and negative emotional effects of humans on the spatial environment. Studies of wayfinding behavior in urban spaces and points of



interest on building facades have mainly analyzed the arousal aspect of emotion.

Figure 3. Valence-Arousal model

Human emotion perception of the spatial environment is complex. An urban environment, many elements of the spatial environment affect human emotion perception, not only urban spatial components (such as road width, whether there are street lights and seats, building scale, and facade) will have an impact on human emotion, but also the light, temperature and social factors (whether there are people around, the influence of traffic vehicles in the environment) will have a The light, temperature, and social factors (presence of people and traffic in the environment) also have a significant impact on human emotions. In urban space, it is impossible to ignore the influence of disturbing environment on the study, and how to control the environmental disturbance should be the next issue to be considered in the study. Since the architectural space is mainly located indoors, the factors affecting mood change are conducive to controlling environmental variables compared to outdoors, which is more helpful for the experiments to exclude the effects. On the other hand, the measurement and classification of human emotions in the study are relatively single, and more studies can only analyze the influence of spatial environment on human emotions positively or negatively. However, the deeper emotions cannot be analyzed and expressed.

4.3. SPATIAL FEATURES AND PHYSIOLOGICAL SIGNALS (QUESTION 3)

We tried to obtain the relationship between spatial features and physiological signals in related studies by categorical analysis (Table 3). The main spatial environmental features used in the study about the influence of spatial environment features were EEG, ET, GSR, HR, EDA, and PPG. the EEG was used to study the influence of spatial types on humans. The GSR was used to study the influence of spatial, physical environment on humans with human facial expression features. Building surface

concerns EEG is used in the study of wayfinding behavior.

The physiological signals used are related to the characteristics of the spatial environment under study, and also, the content of the study impacts the physiological signals used. Focusing on human emotional changes mainly uses EEG and physiological signals such as EDA and GSR, where EEG is the primary way to detect human emotions. Focusing on physical characteristics in the spatial environment, such as temperature comfort research, in addition to focusing on human's emotional responses, about human body physiological function responses are also among the practical concerns.

Table 3. Spatial features and physiological signals

Research Subjects	Sensors	Reference
Structural characteristics of the spatial environment	EEG ET GSR HR EDA PPG	N=19
Building space type	EEG	N=3
physical environment of the building space	Facial Action GSR	N=1
Points of interest on building surfaces	ET	N=1
Spatial environment pathfinding behavior	EEG	N=2

5. Conclusion

Human beings are now living in an increasingly wide variety of scenes that stimulate neural perception and emotional changes all the time. It is essential to understand the impact of different life scenes on human emotion perception, and it also helps quantify the spatial characteristics corresponding to human emotion objectively. With the support of modern technology, it is possible to quantify human emotions objectively: 1) using physiological data as the evaluation index of spatial design, quantifying human emotions evaluates this initially subjective behavior objective; 2) from the perspective of people themselves, using the user's emotional data as a direct source of design reference, making the evaluation of design features more data-supported.

However, studies on human emotions to assess spatial design features are still in the minority. First, the associated technical difficulties may pose a threshold for research scholars. Second, non-research influences in the objective environment become the primary source of interference in experiments. At the same time, the current research still has more lacking aspects, 1) in the use of physiological signal sensors, it is ideal to use EEG technology to analyze human mood changes. However, the device itself has limitations in the way it is worn and the scenario in which it is used, the way to reduce the impact of the device itself is to conduct experiments in the laboratory; 2) In terms of using the spatial environment to influence people's emotions, the spatial environment has a milder effect on human emotions, and people's emotional responses to changes in the spatial environment are more subdued, requiring the use of

more sophisticated physiological sensory equipment for detection, such as the use of EEG technology.

As an intersection of architecture, neuroscience, and psychology, it has a broad research prospect to analyze the influence of spatial environment on human emotion perception. With the continuous enrichment of human life scenes, human's mental needs for space are increasing, and quantifying spatial emotional characteristics can help advance human understanding of the spatial environment affecting human mental health and emotional perception.

In today's rapidly developing human technology, people's lives are changing rapidly, and new products and devices are constantly flooding the spatial environment where people live. However, the research on the emotional perception of features in the spatial environment has been in a vacant state. By analyzing the research on human physiological perception of spatial environment in recent years, we continue to promote the research on the emotional characteristics of human spatial environment by summarizing the application of physiological signal technology, architectural spatial characteristics and emotional classification.

Acknowledgements

This research was supported by the following funds: Later Funded Projects of National Philosophy and Social Science Foundation of China (No. 19FXWB026); Youth Project of National Natural Science Foundation of China (No. 51908158); Higher Education Research and Reform Project of Guangdong Province (No. HITSZERP19001); General Project of Stabilization Support Program of Shenzhen Universities (No. GXWD20201230155427003-20200822174038001); Shenzhen Excellent Science and Technology Innovation Talent Training Project (No. ZX20210096).

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