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Systematic Review

Research Contents, Methods and Prospects of Emotional Architecture Based on a Systematic Literature Review

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Abstract: In recent years, research on building perception has increasingly become a hot topic. More and more scholars have explored the user perceptions of the built environment and guided the design through the perception results. The technical method of emotional engineering can quantify people's emotions and facilitate the exploration of users' perceptions in the built environment. However, most of the existing research is empirical, and there is no article to review the interdisciplinary direction of architecture and emotional engineering. This review uses the PRISMA method to conduct a systematic literature review of 147 studies on building environment assessment using emotional engineering methods, and discusses the relationship between the building environment and humans, especially in terms of emotions, cognition, behavior, and physiology. Through a systematic literature review, the theoretical basis of emotional architecture is put forward. It constructs the interactive mode and theoretical framework of emotional architecture and reveals that the combination of artificial intelligence, big data and machine learning may be the new direction of emotional architecture research in the future.

Keywords: emotional architecture; built environment cognition; emotional engineering

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1. Introduction

As a space inseparable from human production and life, architecture and the environment have a profound impact on many aspects of human beings. At present, most scholars have studied how architecture meets people's basic needs, such as building scale, building structure, building function and layout. However, with the development of the economy, people's demand for spiritual values presented by buildings and environments is becoming more and more prominent, which has motivated more scholars to pay attention to the impact of architecture on people's emotions, cognition, and behaviors, as well as physiological and psychological health. For example, it has been found that an increase in the rate of greenscape can relieve people's stress [1], and the transparency of the street interface affects people's eye movement data [2]. These studies show that buildings and their environments can have an impact on human emotions and cognition.

Bloomer and Moore, referring to architecture as a field of study, state that "little reference is made to the unique perceptual and emotional capacities of human beings" [3]. A visually oriented approach to architectural expression has resulted in the visual experience overriding other sensory effects [4]. However, the experience and feelings of architectural design are also governed by perception. Pallasmaa states that "all experience implies the act of recalling, remembering and comparing" [5]. Emotional feelings and memories can provide new design ideas for architecture.

Emotional engineering is an approach that analyzes how a product design or service evokes specific emotions in users. It is based on the idea that emotions play an important role in human decision-making and behavior and assists designers in designing products that evoke positive emotions in users. This user-centered design method can be used to analyze how buildings and their environments evoke emotional changes in users. Some studies have shown that built environment design elements, such as space, landscape, light, color, texture and materials, evoke specific emotions. Most current research has focused on single-sensory attributes, for example, examining the effects of changing lighting or wall color (hue) [6–9], or simply adjusting the brightness of ambient lighting [10,11] on human emotions. This uni-sensory (and sometimes uni-dimensional) approach is undoubtedly relevant as it can help simplify the study of how design affects the emotional experience of users [12]. More importantly, this approach also fits perfectly with the modular approach to thinking that became very popular in psychology and cognitive neuroscience in the late twentieth century [13]. However, this single-sensory approach to research ignores the fact that the human emotional experience has a multisensory character, as well as proven cross-sensory interactions.

Most of the existing research is empirical, and there is no interdisciplinary review of emotional engineering and architecture. Therefore, based on the interdisciplinary nature of this research direction, this paper uses the PRISMA method to summarize its development status and research content to summarize its theoretical basis. The following sub-objectives were developed to examine this research question:

- Provide a global perspective on the background, trends, lines of research, and results of the development of emotional engineering techniques in the application of architecture;
- Outline the ways in which architecture and emotional engineering interact;
- Construct a theoretical framework for emotional–architectural interactions;
- Provide a solid theoretical basis for the interdisciplinary subject of architecture and emotional engineering and discuss future research directions.

2. Foundations of Interdisciplinary Research

Based on the interdisciplinary nature of architecture and emotional engineering, it is necessary to analyze the research basis of this research direction. This section analyzes the nature of interdisciplinary research by using CiteSpace 5.7 R5 to explore its development process and research methods.

2.1. Previous Research Methods

The essence of the cross-study of architecture and emotional engineering is to use empirical research methods to evaluate the building environment and optimize architectural design. Therefore, it is necessary to analyze the frontiers of the evaluation of the built environment. Keyword clustering mapping can summarize the similarity between the nodes of each keyword, cluster the nodes with obvious co-word relationships into one class based on data operation, and accurately depict the focus of the research frontier [14].

In this section, CiteSpace 5.7 R5 information visualization and analysis software was used to visualize and analyze the journals on the topic of "Built Environment Assessment" in the Web of Science. The results are shown in Figure 1. CiteSpace keyword mapping generated a total of six items, Modularity $Q = 0.491 > 0.3$, clustering is significant, Silhouette = $0.729 > 0.7$, and clustering confidence is high. The research on built environment evaluation is centered on six themes: thermal comfort, physical activity, GIS, Internet of Things, corrosion, and CFD (Figure 1).

In order to be able to intuitively present the evolution process and development trend of keywords in different time periods, time-zone visualization of keywords was performed in an attempt to analyze the research characteristics of the field of built environment assessment from 2012 to 2023 and the mainstream of research at each stage, so as to explore the dynamic evolution of the field of built environment assessment. Figure 2 shows the overall time-zone diagram of built environment evaluation, which shows the evolution of keywords in the time dimension, and can clearly and intuitively discover the research trend of built environment evaluation. From the figure, it can be seen that 2012–2014 had the least number of nodes and the fewest lines, and this period of time was the starting exploration period of the built environment evaluation. After 2014, the research on built space evaluation is more in-depth, and the keywords are densely distributed with a wide range of topics (Figure 2).

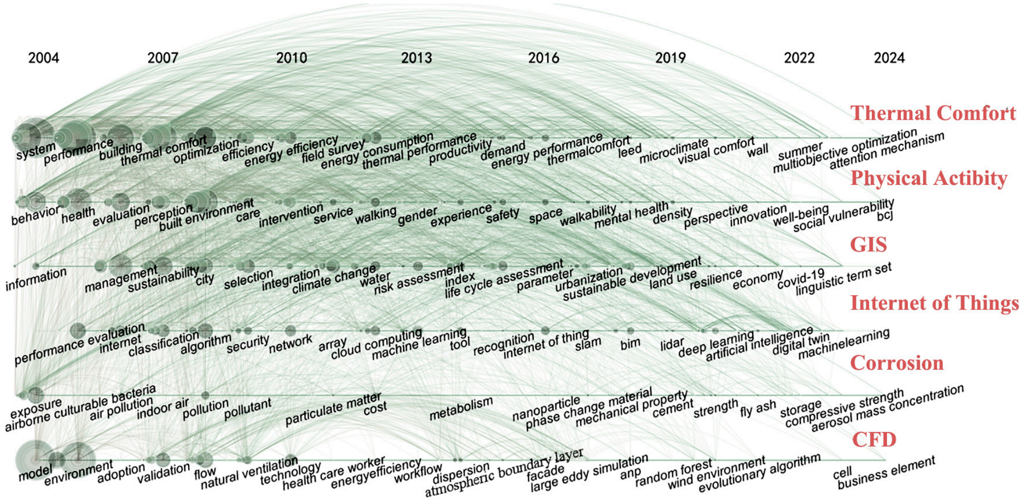

Figure 1. Clustering of keywords for built environment evaluation.

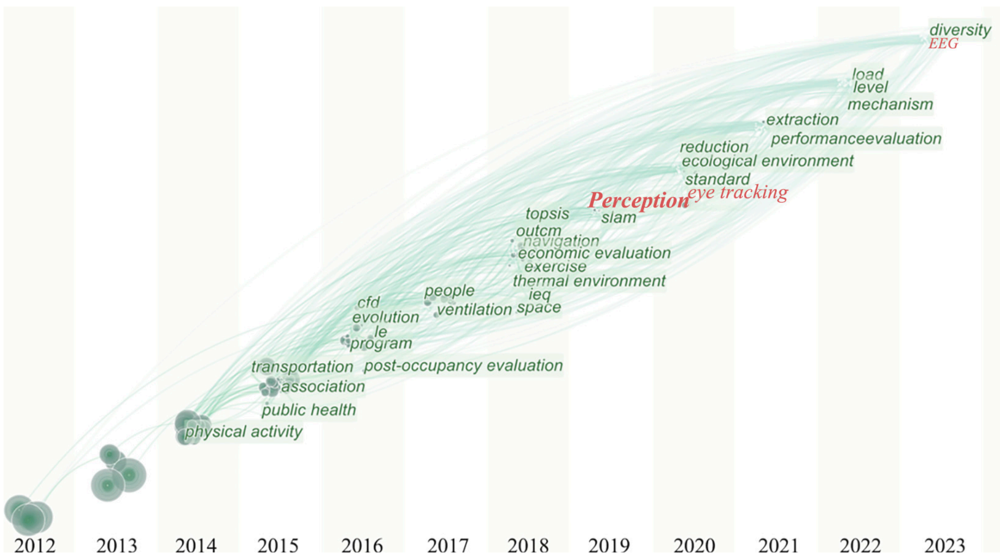

Figure 2. Overall time-zone diagram for built environment evaluation.

Combined with the scientific knowledge map of keyword clustering for the evaluation of the built environment in Figure 1 (timeline view), it is possible to see the time span of the literature related to a particular research topic. At the beginning of the research period, researchers usually evaluated the built environment through behavioral activity observation and post-use evaluation, and from 2019 onwards, researchers began to study "perception". By 2023, research on the evaluation of the built environment will become more and more diverse, including hot keywords, such as EEG, visualization, and quantification. As a result, the use of quantitative methods is essential in built environment evaluation research. In the current literature, despite the growing number of empirical studies to quantify the relationship between human perception and the built environment, there are few articles that provide a systematic review of the existing literature, so this paper reveals the research progress, methods, and potential by conceptualizing this research topic.

2.2. Methods for Quantifying Human Emotions

Perception is the reaction process of the human brain to information. It is a series of processes in which the user's consciousness perceives, feels, pays attention to and perceives the internal and external information. From the perspective of psychology, it can be divided into two processes: sensation and perception. Feelings are a direct reflection of individual attributes of the human brain acting directly on each sensory system; it is the body's instinctive response. It can be measured objectively by eye tracking, skin conductivity level, brain activity, heart rate and facial expression. Perceptions, on the other hand, are the overall process of observation, feeling, integrated processing and interpretation of stimulus objects by the human brain. It is generally measured using self-report instruments, such as interviews, surveys, questionnaires, rating scales and self-assessment procedures [15].

In order to determine how users perceive the built environment, the focus is on its scientific measurement. Emotional engineering focuses on the emotional needs of the user, and is a research method that conforms to the concept of "human-centeredness". Its essence is to use quantitative methods to measure the physiological, psychological and behavioral responses of users, focusing on the comfort and pleasure of users when using products and other aspects of demand, so as to carry out product design (Table 1).

Table 1. Measures of emotional engineering.

Typology		**Subjective Measurements**	**Objective Measurements**	**Clarification**
Psychological Measurements (Cognitive measurements)	Verbal	Self-reporting methods: questionnaires, interviews, field surveys, etc. Semantic Differences Comparison Method	Oral Analysis Method	Intuitive and can avoid semantic differential perception
	Non-verbal	PANAS measuring method PrEmo measurement Probe detection method etc. SAM self-assessment, etc.	PAD measurement Emocards measurement Questionnaires etc.	
Physiological measurements		Expressive behavioral measures: facial expression measurements, eye tracking, etc.	Instrumental measurements: heart rate, blood pressure, skin electricity, EEG, etc.	Capture emotional changes quickly and accurately
Behavioral Measurements		-	Expressive behavioral measures: observation, video, etc.	Relatively inefficient, more effective in combination with objective measures

3. Materials and Methods

A literature review is a comprehensive introduction and elaboration of research in a related direction by searching the literature and presenting further insights. There are various types of literature reviews, and this section first analyzes how people react to their surroundings and then provides an in-depth analysis of the research on the evaluation of the built environment using quantitative perception methods through a systematic review and meta-analysis (PRISMA) approach [16]. It systematically reviews the application of this methodology in architecture and analyzes the current state of its research.

In this study, six literature search databases were selected, namely, the Web of Science, PubMed, IEEE Xplore, SpringerLink, Scopus, and ScienceDirect. Boolean logic was utilized for the retrieval statement narration. The basic logical retrieval formula was: (Architecture* OR Urban* OR Environment OR Space) AND (Emoti* OR Brain* OR EEG OR ECG OR EDA OR Psysico* OR Behavioral OR Gesture OR Cogni* OR Affect* OR "Eye tracking" OR "Facial expression") [16]. Due to the different lead words in each database, the search themes for each database are shown in Table 2.

Table 2. Literature databases and search terms.

Source	Search Terms Protocol
Web of science	(Architecture*[Topic] OR urban*[Topic] OR environment[Topic] OR space[Topic]) AND (emoti*[Topic] OR brain*[Topic] OR EEG[Topic] OR ECG[Topic] OR EDA[Topic] OR Psysico*[Topic] OR Behavioral[Topic] OR Gesture[Topic] OR Cogni*[Topic] OR Affect*[Topic] OR "Eye tracking"[Topic] OR "Facial expression"[Topic]) AND ("Construction Building" OR "Urban Studies") AND(SCI OR SSCI)
PubMed	(Architecture*[Title /Abstract] OR Urban*[Title /Abstract] OR Environment[Title /Abstract] OR Space[Title /Abstract]) AND (Emoti*[Title /Abstract] OR Brain*[Title /Abstract] OR EEG[Title /Abstract] OR ECG[Title /Abstract] OR EDA[Title /Abstract] OR Psysico*[Title /Abstract] OR Behavioral[Title /Abstract] OR Gesture[Title /Abstract] OR Cogni*[Title /Abstract] OR Affect*[Title /Abstract] OR "Eye tracking"[Title /Abstract] OR "Facial expression"[Title /Abstract])
IEEE Xplore, SpringerLink, Scopus, ScienceDirect	(Architecture* OR Urban* OR Environment OR Space) AND (Emoti* OR Brain* OR EEG OR ECG OR EDA OR Psysico* OR Behavioral OR Gesture OR Cogni* OR Affect* OR "Eye tracking" OR "Facial expression")

* means that the variants related to this root can be searched.

Due to the large amount of data retrieved from the papers, including from papers not related to this study, the authors performed two rounds of manual screening by reading the titles and abstracts of the articles and the full text. As shown in Table 2, the inclusion criteria for the papers were: related to the architecture or planning industry, related to architectural design, environmental design, and urban design, researched through empirical studies and written in English. All searches and exclusions were performed over a four-month period from July to October 2023 to maintain the standardization of the data (Table 3).

Table 3. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Essays Related to Architecture or Planning Industry	Not an architectural or planning industry-related paper
Related to architectural design, environmental design, urban planning	Not related to architectural design, environmental design, urban planning
Empirical studies	Literature reviews, commentaries or meta-analysis
Written in English	Written in other languages

As shown in Figure 3, this study strictly applied the PRISMA methodology process for retrieval and screening, which includes five steps: (1) literature search; (2) de-weighting using Microsoft Excel 365; (3) screening by analyzing titles and abstracts; (4) screening by analyzing the full text; and (5) analyzing references. A total of 73,597 articles found in the database were analyzed. A total of 73,405 articles were excluded by analyzing article titles and abstracts. Subsequently, a full-text review of the remaining articles was conducted to exclude 46 articles that were not conducive to answering the questions posed according to the exclusion criteria, and the remaining 146 articles were included in the analysis, followed by the inclusion of one additional article in the analyzed database by analyzing the references. Finally, we obtained 147 articles for the systematic review [1,2,17–161] (Figure 3).

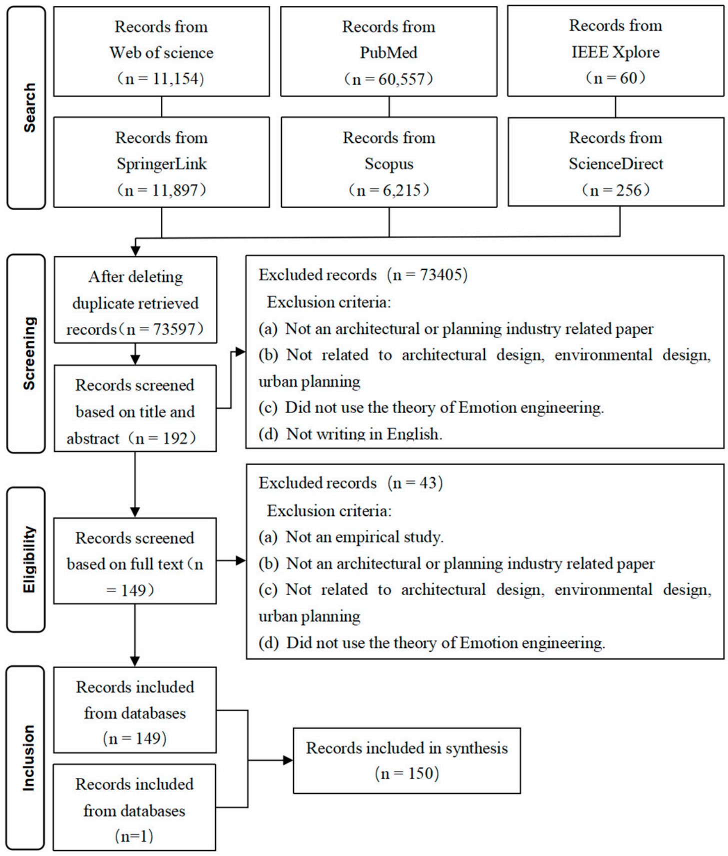

Figure 3. Inclusion and exclusion flowchart for articles.

4. Result

As an emerging field of architectural research, a total of 147 citations meeting the search criteria were identified throughout the literature screening process, and Figure 4 presents the proportion of these 147 articles in chronological order. First, it can be clearly seen that most literature was published after 2010, and as time advances, the number of articles issued in recent years has surged in the form of an exponential function. This also shows the gradual increase in people's emotional needs for the built environment with development (Figure 4).

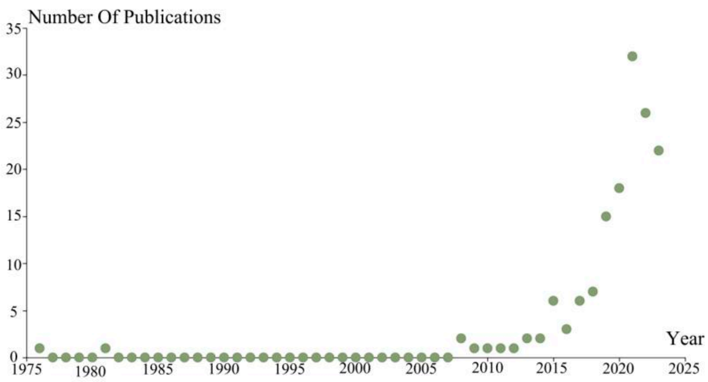

Figure 4. Analysis of the volume and timing of communications.

4.1. Evolution of Interdisciplinarity

As shown in Figure 5, this paper divides the interdisciplinary process between emotional engineering and architecture into four levels: tool and problematic unidirectional support, problematic and toolatic reverse feedback, mediated facilitation and problematic interdisciplinarity birth [162]. Emotional engineering is a tool discipline and architecture is a problem discipline digital tools as a medium to facilitate the interdisciplinary process. This section explores the evolution of emotional architecture from the four levels of interdisciplinarity (Figure 5).

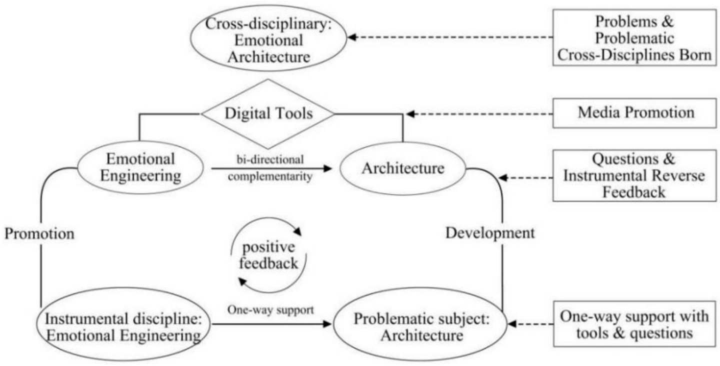

Figure 5. Evolution of cross-cutting disciplines.

4.2. Instrumental and Problematic One-Way Support

Emotional engineering involves a number of steps, including identifying, eliciting, regulating, and measuring emotions. The experiential approach is one method of identifying emotions, where individuals identify and label their emotions based on subjective experiences. This method requires individuals to pay attention to their internal states and feelings. The level of regulation of emotions and the ability to transition from a state of alertness to a state of calm is related to the flexibility of the autonomic nervous system [163]. While the empirical approach is valuable for self-awareness and emotion regulation, it may not always be accurate or reliable because emotions are intricate and there may be personal biases or blind spots that affect people's ability to accurately identify and label their emotions. Therefore, it is important to supplement this approach with other forms of emotion recognition, such as behavioral feedback from subjects or physiological measures. As shown in Figure 6, the dependent variables of the empirical study are summarized as physiological data, behavioral data and cognitive data, and the following section explores the ways in which emotional engineering techniques are captured and used on these data in each of these three areas (Figure 6).

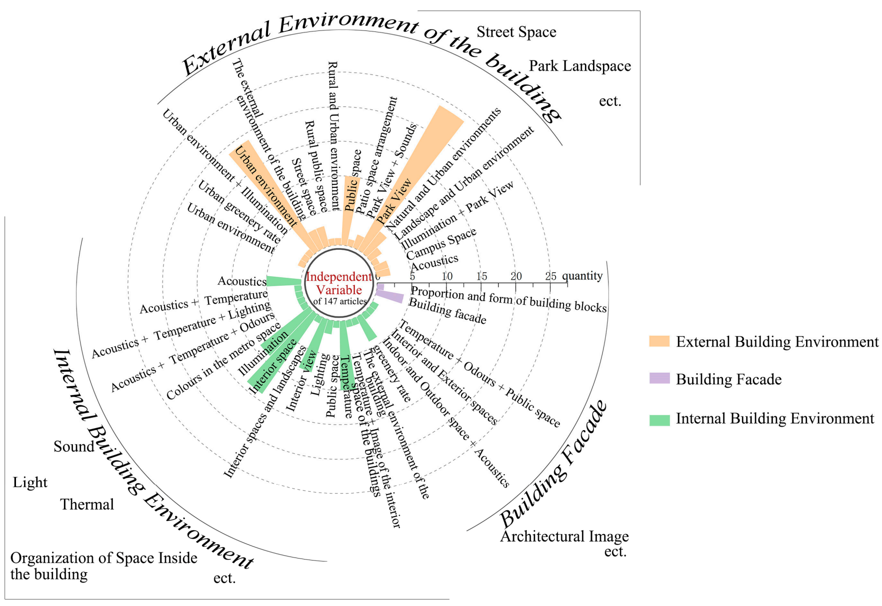

Figure 6. Classification of emotional engineering techniques.

4.2.1. Cognitive Data

In addition to nonperceptual behavioral data, cognitive data, such as questionnaires, speeches, speech, text, and other forms of data, can be used to model emotions for building design and environmental assessment. Physiological measurements provide an objective and quantitative approach to emotion recognition. By measuring physiological changes such as heart rate, researchers can identify patterns and markers associated with specific emotions, improving the accuracy and reliability of emotion recognition models.

Considering the relationship between buildings, people and the environment, the researchers developed an integrated judgment model and a comfort–satisfaction matrix to assess the ability to regulate the performance of the built environment in passive spaces [164]. Questionnaires have been used to assess the impact of design elements on emotional responses. For example, one study investigated the emotional impact of curved versus straight lines in interior environments and found that curves evoked more pleasant and less agitated emotional states [165]. The presence of interior design elements, such as landscape posters, paintings, plants, and furniture, has been shown to elicit more positive emotional responses in virtual hospital rooms [166]. Questionnaire-based surveys have also been used to investigate emotional responses related to architectural heritage, indoor climate and comfort [167]. These survey studies provide design ideas that can have a positive impact on enhancing environmental comfort.

The integration of cognitive data, including questionnaires and other forms of data, enriches the interpretation of emotional responses in architectural design and environmental evaluation. By considering both perceptual and cognitive aspects, researchers can develop more comprehensive models to capture the complexity of human emotions toward buildings and their environments.

4.2.2. Physiological Data

The field of architectural and environmental studies has utilized neuroscience to study how the built environment affects human perception [168]. Objective experimental methods based on physiological data are being used to explore the relationship between architecture, humans, and the environment. Physiological measures in emotion recognition rely on the realization that emotions are accompanied by specific changes in the body's physiology, such as heart rate, blood pressure, skin conductance, and brain electrical changes. These changes can be objectively measured with instruments such as electrocardiogram (ECG), electrodermal activity (EDA) and electroencephalogram (EEG).

Several studies have applied neuroscience techniques to understand the effects of architectural elements on human perceptual and cognitive performance. For example, using EEG and virtual reality techniques, researchers observed significant changes in EEG responses when participants experienced different architectural elements. These changes were indicative of arousal responses, with different levels of arousal depending on the specific architectural features [57,169]. Other studies have investigated the use of neurophysiological data to characterize design features and functional effects. By measuring EEG and heart rate, the researchers found that users were more relaxed when experiencing the new office, particularly the café space, compared to the old office. This suggests that neurophysiological data can provide insights into the impact of design on individuals [170]. The effects of urban environments [133,171], crowding on emotional responses in older adults [172], the effects of natural landscapes on psychophysiological states [24], and the modulation of auditory cortical connectivity by visual environments have also been explored through physiological signaling studies [173]. Neuroscientific methods have also been applied in construction as a means of tracking the emotional health of workers and assessing potential hazards. Applications of neural signals, such as EEG, have been shown by researchers to be effective in assessing mental workload and detecting stress in construction workers. These applications have the ability to improve worker safety, physical and mental health, and productivity [174,175].

Neuroscience techniques are similar to the physiological measurement aspects of emotional engineering techniques. The use of emotional engineering techniques plays an important role in obtaining quantitative data on the relationship between the built environment and human emotions. Objective and quantitative methods of analysis are an effective complement to subjective experience and facilitate the design and evaluation of perceptual buildings and environments.

4.2.3. Behavioral Data

The use of behavioral data has facilitated the creation of emotional models for building design and environmental assessment. Researchers have employed a variety of techniques to capture and analyze facial expression signals to be able to identify emotional arousal, stress, fear, and pleasure [176].

There have been many experiments using video cameras and facial expression recognition software to study human emotional responses in different environments [177]. For example, analyzing the effect of virtual museum tours on visitors' emotions by recording facial expression signals revealed that online museum experiences can be as engaging as physical tours [49]. Facial expression recognition technology has also been used to explore the effects of glass-framed buildings on human responses and psychological comfort, showing that glass structures can create a comfortable and positive emotional environment [178]. Virtual reality and facial expression analysis have been combined to assess human responses to different lighting environments and to help architects obtain user feedback during the design phase [179]. These methods provide valuable insights into human behavior and help design lighting environments that are more responsive to user needs [180]. Researchers have also utilized automated facial expression recognition and virtual visual stimuli to quantify general human responses and psychological comfort trends of building occupants. This approach has proven effective in supporting the architectural design process and assessing the vibration comfort of pedestrian-glazed structures [51,181]. Combining a decision support system with a facial expression recognition methodology has been applied to case studies of retrofit programs showing a positive impact on the emotional state of the occupants. Additionally, studies have examined the relationship between nearby nature (trees and grass) and mental fatigue and work levels in urban public housing [182,183]. However, in terms of behavioral techniques, researchers have studied relatively few changes in posture and gestures brought about by the built environment, which may be related to the fact that people from different cultures have different levels of gesture presentation [184].

The use of behavioral data, especially facial expression signals, provides an effective method for interpreting emotional responses, psychological comfort, and human behavior in architectural and environmental contexts.

4.3. Problem and Instrumental Reverse Feedback

The design of architectural spaces has a significant impact on the emotional response of users. Factors such as size, shape, typography, and sensory modalities can have an impact on the emotional experience within a building [185,186]. Gifford [187] and Nasar [188] emphasize the evaluative nature of people's perception of architectural spaces, suggesting that certain design elements can evoke either positive or negative emotions. Milligan explores the role of historical context in shaping the perception of architectural spaces and the emotional experiences associated with it [189]. Emotional impacts of spatial environment design can be better understood through empirical research on effect measures of space-related interactions, focusing on the integration of space, technology, and user experience from the perspective of affective research, and validating and interpreting affective measures in architectural space.

This shows that the physical and environmental properties of buildings evoke the psychological emotions of people in a given situation, which is a very interesting research topic worldwide today. Users interact with their surroundings instinctively, and elements of the built environment can stimulate emotional changes in people. These elements are, on the one hand, physical properties of the entity (space, color, texture, form, etc.) and, on the other hand, environmental factors (light, sound, temperature, humidity, etc.) [190]. Therefore, we categorized the built environment, as shown in Figure 7, based on the spatial hierarchy to divide the elements of the built environment into the physical elements of the building facade, the internal environment elements of the building and the external environment elements of the building (Figure 7).

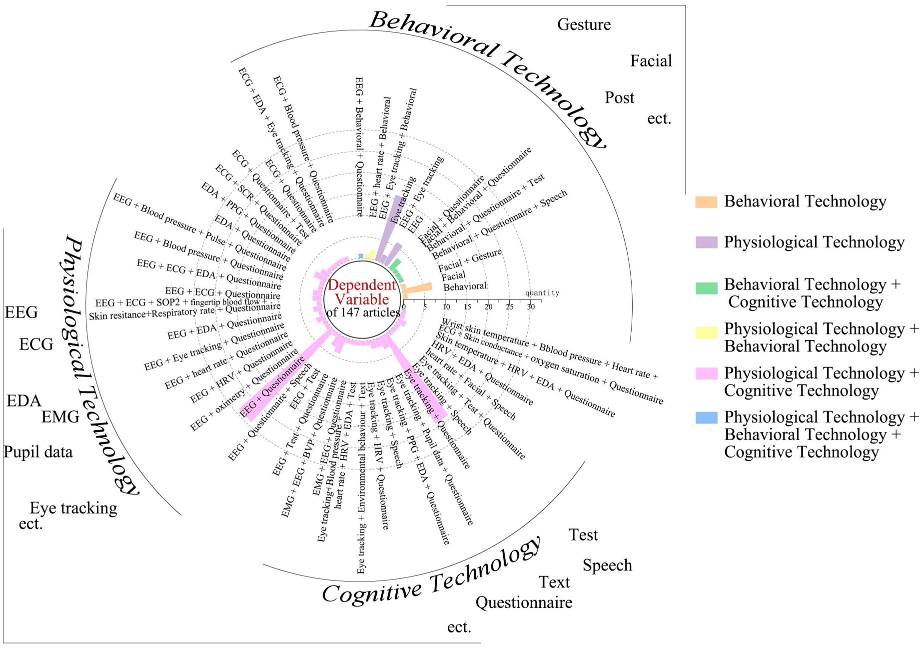

Figure 7. Classification of elements of the built environment.

4.3.1. Building Facade

Out of the 147 empirical studies included, only five papers were studies on how building monolithic elements brings about emotional changes in subjects. These were studies of building distribution forms, block aspect ratios [38] and building elevations [46,53,55,144]. These studies give designers an empirical basis for understanding which building monolithic designs are preferred by users.

It is worth discussing why architects seldom evaluate the design of a single building individually. At the beginning of the 20th century, American architect Frank Lloyd Wright put forward the idea of organic architecture, emphasizing the close relationship between buildings and their surroundings. He believed that buildings should be integrated into the natural environment and coexist harmoniously with it. Wright's proposed concept of organic architecture emphasized the functionality, locality and sustainability of buildings, and did not provide important inspiration and guidance to later architects and designers [191]. Therefore, the architectural design process can not only consider the single building and ignore the surrounding environment; the beauty of the building depends largely on the harmonious relationship with the surrounding environment.

4.3.2. External Building Environment

The design of the external environment of a building directly affects people's quality of life, the sustainability of the building and the overall quality of the urban environment. In the previous design process, designers always used subjective evaluation as the evaluation standard of the external environment, and there was no data support to prove the advantages and disadvantages of the design solutions of the external environment of the building. Therefore, the use of emotional engineering techniques can quantify people's emotional indicators as a basis for designers to evaluate and compare solutions.

Among the 147 empirical studies reviewed, 82 studies were on the external environment of buildings. For example, Franek Marek explored the effect of natural versus urban environments on people's eye movement data by examining subjects' eye movements [46]. Zhu, Xun et al. quantified photographs extracted from social networking sites and examined the facial expressions of the people in the photographs in order to study the differences in emotions in urban green spaces. The study showed that the higher the Normalized Vegetation Index (NDVI) value of urban green space, the higher the probability and intensity of emotions occurring in the green space, and the more happy emotions people show [54]. These empirical studies show that it is feasible to use emotional engineering techniques to measure the emotional changes brought about by the built external environment. The data are analyzed to reveal the effects of different external environmental elements on users' emotions and moods. This can help to improve the design of exterior building spaces in order to create more human-centered exterior building environments that satisfy people's emotional needs for their environments.

4.3.3. Internal Building Environment

As a key place for people to live, work and interact, the interior space of buildings is the backdrop of our daily lives and directly affects the emotions, health and quality of life of its occupants and users. Therefore, it becomes crucial to study and optimize the interior space of buildings. Many scholars have already studied and proposed indicators and norms for some elements of the interior environment of buildings, such as lighting, air quality indicators, acoustic indicators, temperature and thermal comfort indicators. These indicators and norms usually focus on physical parameters and rarely address human emotional needs. However, the internal environment of a building also has a significant impact on human emotions and moods, so it makes sense to study the internal environment of a building using emotional engineering to quantify human emotions.

Currently, there are also many scholars who have used emotional engineering techniques to study how the internal environment of a building affects human emotional changes. For example, Wang Xi et al. used EEG to investigate the effects of the indoor thermal environment on subjects' psychological compliance and task performance, and the results showed that different individuals responded differently to the thermal environment [62]. Agnieszka Olszewska-Guizzo et al. quantified the physiological signals of the subjects to investigate the effects of the indoor windowed environment on the Alpha and Beta bands of the EEG effects. It was shown that brainwave patterns normally associated with positive emotional states, motivation and visual attention mechanisms may increase with the degree of green coverage within the view [126].

Therefore using emotional engineering techniques to quantify the emotional changes brought about by elements of a building's interior environment helps to achieve a more humane design to meet the needs of different user groups. Through the approach of emotional engineering, it is possible to have a finer understanding of how the interior environment can be designed so that factors such as color, lighting, materials, and layout bring a good emotional experience to the user.

4.4. Media Facilitation

Immanuel Kant proposed the theory of "a priori knowledge" in his book Critique of Pure Reason, which argues that human knowledge of the world is limited by innately formed sensory modalities, including vision, hearing, touch, taste, and smell [192]. Some studies have shown that for a normal person, visual information accounts for more than 70% of all sensory information [193]. When the built environment serves as a stimulus for people to produce emotional changes, visual presentation becomes a more convenient and effective way for people to interact with the built environment.

As shown in Figure 8, among the screened databases, the emotional engineering experiments used Realistic Environment, Picture, Video, Cave Automatic Virtual Environment (CAVE), and Virtual Reality (VR) for the presentation of the built environment. Since the principles of these five presentations are different, they are categorized into Realistic Environment, 2D Multimedia Environment and Virtual Reality Environment by analyzing their presentation principles. The following section will analyze these three interaction modes separately and explore the research status, advantages and disadvantages of the three interaction modes (Figure 8).

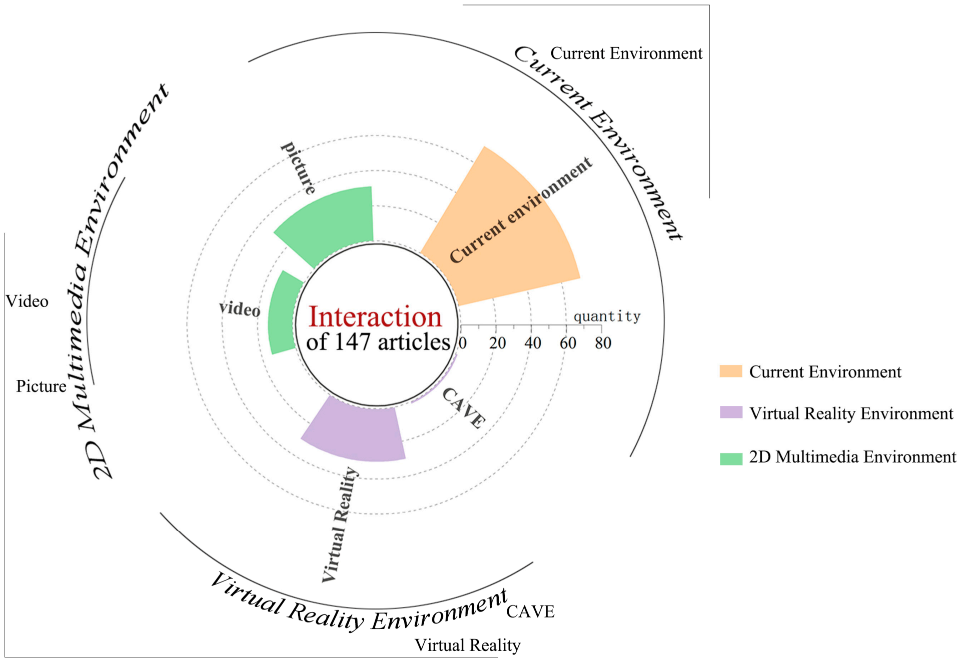

Figure 8. Interaction diagram.

4.4.1. Current Environment

Nearly half of the scholars in the included literature chose to conduct their experiments in the real environment, and this way of presenting the experimental independent variable is not only more realistic, but also greatly reduces the time needed to collect experimental materials. This enables the experiment to provide more intuitive, comprehensive, and rapid feedback on the emotional changes brought about by the built environment in order to achieve an objective method of evaluating the current environment.

The current state of affairs has been evaluated by many studies through emotional engineering techniques. For example, Simpson, James et al. verified how pedestrians are visually exposed to different elements of streets and street edges in real-world environments through the use of mobile eye-tracking glasses [21]. In order to investigate the neurocognitive state of subjects in real-world environments in typical urban environments and in urban green environments, Ilker Erkan et al. collected and interpreted heart rate, EEG, and eye-movement data and behavior, and it was found that the urban green environment had a more positive effect on the subjects [29]. Songtao Hu, in order to avoid using measurement instruments that make people uncomfortable and interfering with the natural state of the human body, investigated the comfort response to the thermoacoustic environment based on facial micro-expressions. He demonstrated that it is possible to compare the results of facial expressions with the results of subjective questionnaires and the predicted mean vote (PMV) by accurately evaluating the comfort of thermoacoustic environments through the recognition of facial micro-expressions [52].

However, empirical studies using realistic environments as experimental environments are only applicable to the evaluation of the current state of the built environment and some environments that cannot be presented using multimedia technology, such as the study of the thermal comfort of the environment. A realistic environment is undoubtedly time-consuming and resource-intensive if it is used to present design solutions. Therefore, the emergence of multimedia technology and virtual reality technology makes the presentation of the built environment more diversified.

4.4.2. 2D Multimedia Environment

Through image processing technology and video technology rendering to generate visual models of architectural designs and environmental simulations, designers are able to explore and present their designs in greater depth, thus improving the quality of the design and the efficiency of communication with the client. In addition to this, the use of images and video also allows for quick documentation of the real environment, avoiding changes to the built environment due to time or other factors. Therefore, the 2D multimedia environment is also a good interactive environment for evaluating the current situation and assessing design solutions.

In the included literature base, there are 45 articles that use pictures and videos as a way of presenting architectural scenes. For example, Yiping Liu et al. evaluated the interaction between forest landscape elements and eye movement behaviors under audiovisual synthesis conditions by having subjects watch a video of a forest landscape, and measuring and recording subjects' eye movement data and subjective evaluations [163]. Ningning Ding et al. asked subjects to view photos of plants in different living environments, and explored people's visual preferences for plant features in different living environments by analyzing subjects' eye-tracking and EEG [151]. Nubani Linda et al. analyzed the impact of virtual tours on viewers, using facial expression recognition software to record and analyze participants' emotional responses during their experience of a cyber museum [53]. It was found that when a significant percentage of architectural details, spatial transitions, and product details are captured during the construction of a cybermuseum, which may be just as engaging as visiting the museum in person.

In summary, the use of 2D multimedia technology can indeed present realistic environments or design solutions to subjects and stimulate them to produce emotional changes, but it is necessary to capture a large number of architectural and environmental details in the process of realistic environment acquisition. Additionally, it has been experimentally studied that the horizontal viewing angle of human monoculars can reach up to 156° and the horizontal viewing angle of both eyes can reach up to 188° [194]. Therefore, sometimes pictures and videos cannot fully cover the range of the eye's field of view, resulting in experimental errors.

4.4.3. Virtual Reality Environment

The use of virtual reality to visualize design solutions for the built environment has long been demonstrated to be feasible in several experiments. Many of these projects primarily involved the use of virtual reality technology as a tool for architects to better view and understand designs [195]. Recently, there has been an expansion of research on VR technology in the built environment. For example, VR technology has been used to explore design solutions based on empirical research to adapt color environments to the needs of an aging population. By simulating real architectural spaces and associated visual elements, designers can more easily perform spatial construction and immersive color rendering [196]. Lin et al. used a virtual reality-based experimental approach to investigate the effects of repeated exposure to indoor environments on people's indoor wayfinding performance under normal conditions and in fire emergencies, and the results showed that VR environments cause as much psychological stress during escape as in as much psychological stress as in real life [148,197]. VR technology allows architects to create immersive virtual environments with the same scale, depth, and spatial relationships as the real space, enabling them to experience and interact with their designs in three dimensions and evaluate different design options. The use of VR technology helps designers to understand the quality of the space and to detect potential design problems before the construction phase [157].

Notably, Cave is a virtual reality projection system developed by the Electronic Visualization Laboratory that displays images in a three-dimensional immersive four-walled room using a real-time, viewer-centric head-tracking perspective, a large viewing angle, interactive controls, and a binocular display [198]. As a type of virtual reality technology, it has also begun to be applied to the visualization of the built environment in recent years. However, there is only one paper in the literature database screened by the authors that uses CAVE as a way of interacting with people in the built environment. Vecchiato, G et al. used CAVE technology to present and evaluate the physiological impacts of architectural indoor spatial scenarios on people back in 2015 [136]. This also provides new interaction ideas for future empirical studies.

4.5. The Birth of a Problem and Problematic Interdisciplinarity

The above article reviews the current state of cognitive and emotional research on the built environment based on the emotional engineering approach. The application of emotional engineering techniques in the field of architectural and environmental design as well as the visual presentation of people and the built environment, are discussed. The advantages and disadvantages of each visual presentation are also discussed.

In summary, this paper proposes a structural diagram to investigate the spatial affective computation of buildings and their environments. As shown in Figure 9, elements of the built environment serve as stimuli to elicit emotions and are visually presented to produce emotional behavior in subjects. The emotional behavior of the subjects is quantitatively calculated through physiological, cognitive and behavioral techniques of emotional engineering. Designers can evaluate the design and improve the design solution through the quantitative data (Figure 9).

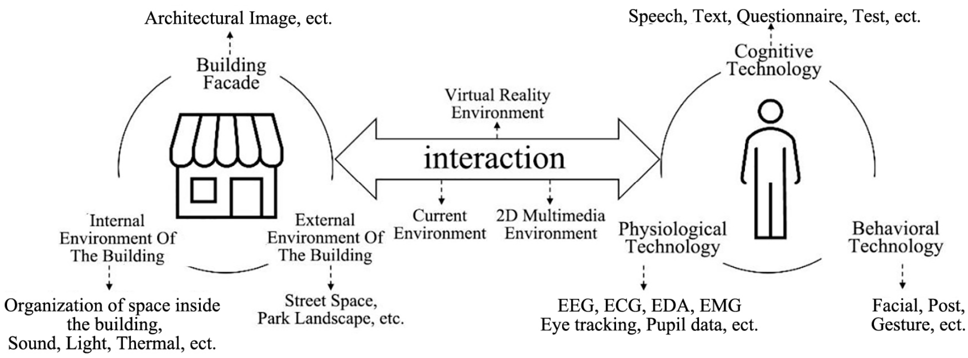

Figure 9. Interactive theoretical framework for emotional architecture.

In order to better describe the interdisciplinary research direction of emotional engineering and architecture, this paper defines this research direction as emotional architecture. Emotional architecture is a discipline at the intersection of architecture and emotional engineering, which focuses on the relationship between human physiological, behavioral, and cognitive responses to buildings and their environments. It is a science that studies how to meet human emotional requirements through design in order to achieve empathy, comfort and pleasing buildings and their environments.

5. Discussion

In order to grasp the essence and development of emotional architecture, this section compares emotional architecture with the previous methods of evaluating the architectural environment, and discusses the future development direction of emotional architecture.

5.1. Differences between Emotional Architecture and Previous Approaches

The essence of emotional architecture is to evaluate the built environment through empirical research to optimize building design. In the existing research, there have been environmental and behavioral research techniques to qualitatively study the built environment [199], and neuroarchitecture to quantitatively study the built environment, as shown in Table 4, which analyzes the theoretical foundations and focuses, research methodologies, fields of application, quantifiability, and strengths and weaknesses of the theories of emotional architecture, neural architecture, and environmental and behavioral research techniques.

Table 4. Emotional architecture vs. pioneer approach.

Theories	Emotional Architecture	Neural Architecture	Environmental and Behavioral Research Techniques
Theoretical foundations and focus	Focuses primarily on the relationship between human emotions, behaviors and cognitive responses and architecture and its environment. Emphasizes the creation of empathetic, comfortable and pleasing built environments by designing to meet human emotional needs.	Emphasizes the impact of architectural design on the human nervous system. To study human physiological and psychological responses in different built environments through neuroscientific methods in order to optimize building design for human health and well-being.	A broader look at the impact of the built environment on people, including social behavior, space use, and environmental psychology. It focuses on the interactions between people and the built environment, using observation and field research to understand how people perceive, use and interact.
Research Methodology	Combining qualitative and quantitative methods, including questionnaires, affective measurements, and simulation experiments to fully understand the relationship between people and the built environment.	Measurement tools from physiology and neuroscience, such as brain waves, heart rate variability, etc., are used to quantitatively assess the physiological response of a person in a given built environment.	Qualitative studies such as questionnaires and field observations are usually used to obtain people's subjective feelings and experiences of the built environment.
Areas of Application	The focus is on optimizing the building design to make it more responsive to human emotional needs.	Mainly used in healthcare, education and workplace design to improve human cognitive abilities, reduce stress and promote health.	It can be applied to a wide range of fields, including urban planning, education, healthcare, commerce, etc. to optimize the design of buildings and urban environments.
Quantifiable	Combines qualitative and quantitative methods for a comprehensive understanding of the relationship between people and the environment.	Emphasizes physiological and neurological measurements, favoring quantitative analysis.	Commonly used qualitative methods such as affective measures and experiential surveys that emphasize subjective feelings.
Advantages	Comprehensive understanding of the relationship between people and the environment through an integrated qualitative and quantitative approach, emphasizing social and cultural factors, with the advantage of practical application.	Providing objective physiological data through physiological and neuroscientific measurements, focusing on the impact of buildings on health.	Focus on people's subjective feelings and emphasize humanistic care.
Disadvantages	Complexity exists in research.	Complexity, limitations, and higher research costs limit its widespread use.	Subjectivity and lack of scientific character make it difficult to quantify and generalize the use of adaptive technology.

Through theoretical comparison, emotional architecture is found to be a comprehensive understanding of the relationship between people and the environment by combining the quantitative and quantitative methods of neural architecture with the qualitative research methods of environmental behavior, which is able to complement the deficiencies that exist in the former research, to evaluate the built environment in a more comprehensive and more adequate way, and optimize the architectural design, so as to make the building and the environment where it is situated more in line with the emotional needs of the human beings.

5.2. Future Directions

In order to study the future development direction of emotional architecture, CiteSpace 5.7 R5 information visualization and analysis software was used to visualize and analyze the journals on the topic of "emotional architecture" included in the Web of Science. As shown in Figure 10, the time-zone diagram of emotional architecture is used to analyze the current development and future trends of emotional architecture in the past ten years. 2014–2019 is the beginning period of emotional architecture, and the research on the emotion of architecture is gradually increasing. From 2020 onwards, keywords such as deep learning, IoT, big data, machine learning, etc., account for the majority of emotional architecture research topics, which is also consistent with the IoT clustering research in Figure 1. There is a consequent indication that the future direction of emotional architecture will be combined with technologies such as Artificial Intelligence and Generative AI. Emotional Architecture experimental data through machine learning, assisted by artificial intelligence technology to generate a big data model of emotional architecture, to promote the training of emotional architecture generative AI. The direction of development of emotional architecture generative AI can solve the current problem of the complexity of emotional architecture research. Data-enabling and AI-enabling emotional architecture metrics can more quickly and easily optimize architectural design, meet human emotional needs, and create empathetic, comfortable, and pleasing architectural environments.

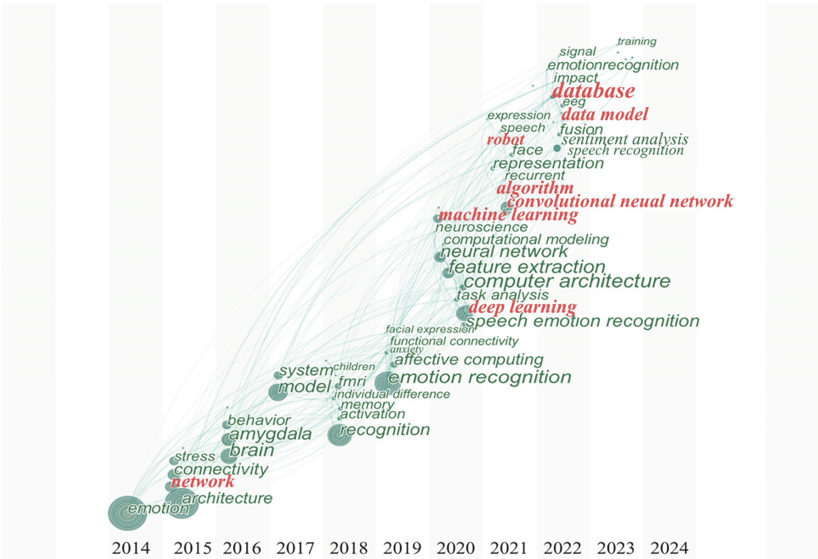

Figure 10. Overall time-zone diagram for emotional architecture.

5.3. Limitations

Although this article contributes to the theme of cognitive and emotional research on the built environment based on perceptual engineering, there are some limitations in the process of the exposition. First, in the process of addressing the theoretical framework of perceptual architectural interaction, this study can only be categorized into the broad categories of buildings and their environments without being able to perform detailed categorization. These detailed studies can only be selected and analyzed in depth by the researcher according to the researcher's angle of concern in order to capture the emotional changes of different architectural or environmental elements on the subjects. Secondly, as this paper used the inclusion criteria for the systematic literature review, articles written in languages other than English were not considered in the inclusion process, and the results might have been more comprehensive if non-English articles had been included in the analysis. Finally, this paper involves multiple disciplines that may have important references that were not found. Moreover, the systematic literature review screening of articles and discourses is a lengthy process, during which new articles may have been published and not included in the analysis.

6. Conclusions

In this systematic literature review, emotion is identified as an important measure for evaluating whether a building and its surroundings meet the needs of its users. Analyzing users' emotions using an emotional engineering approach is seen as an important means of improving the built environment. In this study, we adopted a systematic literature review method to statistically analyze the relevant empirical research papers, focusing on the independent variables, dependent variables, and interactive environments involved in the empirical study of the perception of the built environment based on the emotional engineering approach. On this basis, we summarize the spatial affective computing framework of buildings and their environments. Further, this paper explores possible trends and directions for future architectural development. These in-depth analyses provide important references and guidance for future architectural design and environmental planning.

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