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Exploring the Influence of Environmental Characteristics on Emotional Perceptions in Metro Station Spaces

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Abstract: With the rapid expansion of urban metro networks, metro stations, as critical public spaces, not only influence transit efficiency and spatial layout optimization but also play a vital role in shaping users' emotional experiences. This study examines metro station spaces as its primary research subject, exploring the correlation between physical environmental features and emotional perception within the framework of environmental psychology theory. This study adopts an innovative approach by integrating deep learning-based affective computing methods with semantic segmentation techniques in computer vision to systematically evaluate the impact of various physical environmental features and functional spaces on users' emotional perceptions across multiple dimensions. The study provides empirical evidence for assessing and interpreting the relationship between environmental features and emotional perception, thereby enhancing the reliability of the research. The findings, quantified through deep learning methods, identify key factors influencing various emotional perception scores in metro stations. These insights will assist practitioners in gaining a deeper understanding of how metro station spaces impact users' emotional experiences and can be applied to early-stage design and later-stage optimization of metro station spaces.

Keywords: metro station spaces; emotional perception; environmental characteristics; public space optimization

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1. Introduction

1.1. Background and Significance

In recent years, driven by the rapid pace of urbanization and the increasing demands of densely populated urban centers, a global wave of metro construction has emerged, particularly in developing countries and emerging economies, where metros are widely recognized as a critical solution to mitigate urban traffic congestion and enhance commuting efficiency [1]. For instance, since 2000, China's metro network has expanded rapidly, covering 55 cities by 2024, with a total operational mileage of 10,165.7 km [2,3]. This surge has not only facilitated the modernization of urban transportation infrastructures but has also fostered the emergence of metro stations as vital multifunctional public spaces.

Metro stations serve as pivotal nodes within urban public transportation networks, characterized by a high frequency of use and growing significance in contemporary urban settings. In contemporary urban environments, the metro system has become an indispensable element of daily life for urban commuters, particularly in densely populated

cities, where metro stations accommodate substantial passenger volumes. For instance, in cities such as Beijing, Tokyo, and New York, the daily ridership of metro systems exceeds millions of trips, with numerous stations functioning as 24/7 transportation hubs [4]. Furthermore, metro stations have transcended their role as mere transit points for commuters, incorporating commercial, social, and cultural functions, and progressively transforming into vital hubs of urban public life [5–7]. Consequently, the design and optimization of metro stations are intrinsically connected to the efficiency of urban commuting and the overall quality of life for city dwellers.

Although metro stations constitute a critical element within urban transportation infrastructure, the primary emphasis in their design and operation typically revolves around efficiency and functionality. However, this emphasis frequently gives rise to a conflict with users' emotional perceptions. In the quest for optimal commuting efficiency, metro stations often feature dense, repetitive spatial configurations that prioritize streamlined designs, while inadvertently overlooking the importance of spatial comfort and emotional well-being [8]. For example, numerous metro stations, owing to standardized designs, constrained spaces, dim lighting, and stark color schemes, induce feelings of oppression and anxiety among passengers, particularly during rushed commutes [9]. Especially during peak periods, overcrowded conditions, heightened noise levels, and poor air quality intensify this unpleasant emotional experience. While such designs may fulfill the operational demands of the metro system, they frequently neglect human-centric considerations, resulting in fatigue and discomfort in users' emotional perceptions [10]. Therefore, optimizing emotional experiences while maintaining the functionality and efficiency of metro stations has emerged as a critical challenge in contemporary station design.

The prevailing body of research concerning metro stations primarily centers on functional domains, including passage efficiency, spatial layout optimization, and safety enhancement, whereas studies addressing emotional perception remain fragmented and underexplored. Previous investigations predominantly concentrate on the interplay between metro travel behaviors and emotional perceptions. Specifically, one area explores how users' positive or negative emotional perceptions influence their preference for metro travel modes [11,12], while another area delves deeper into the broader influence of the entire metro travel experience on users' emotional responses [13–15]. For instance, at the macro level, research employs social media data to assess the emotional perceptions within distinct metro station domains [16,17]. At the meso level, investigations focus on the psychological and emotional shifts experienced by passengers during emergency evacuations in metro stations [18,19], while at the micro level, studies examine the emotional fluctuations induced by different noise levels in metro environments [20]. Regarding research methodologies, emotional analysis in the existing literature predominantly relies on traditional tools such as questionnaires and interviews, with only a few studies utilizing advanced techniques such as biosensors or social media data. Additionally, the sample sizes in the majority of these studies remain relatively limited. In summary, current research falls short of providing a systematic examination of the relationship between users' emotional perceptions and the environmental features of metro stations from an architectural standpoint. Moreover, there is a conspicuous gap in the utilization of emerging technologies, such as deep learning and computer vision, to conduct large-scale emotional computation and prediction studies. This limitation hampers the development of comprehensive, systematic insights that could inform architectural design practices for metro stations based on users' emotional perceptions.

This study focuses on metro station spaces as the primary research subject, grounded in the principles of environmental psychology, with the aim of investigating the intricate

correlations between environmental features and emotional perceptions. It addresses the following key research questions:

Research Question 1: Which physical environmental features significantly impact the emotional perception of metro station users?

Research Question 2: To what extent do different functional spaces influence the emotional perception of metro station users?

The novelty of this research resides in its integration of deep learning-based emotional computation techniques with computer vision-driven semantic segmentation, enabling the evaluation of how various physical environmental features and functional spaces shape the emotional perceptions of metro station users. The adoption of innovative statistical methods enhances the value of this study, as they furnish empirical evidence crucial for assessing and elucidating the aforementioned relationships. This methodological approach can serve as a critical tool for addressing challenges related to emotional perception computation within physical spaces, thereby enhancing the reliability of research findings and shedding light on the role of physical environments in shaping emotional perceptions. As a result, the statistical data derived from this approach will empower practitioners to gain more profound insights into the ways in which the features of metro station spaces influence users' emotional perceptions and can be effectively applied to the early-stage design and continuous optimization of metro station environments.

1.2. Literature Review

Metro stations, as pivotal transportation hubs within urban settings, typically prioritize functional requirements, including the optimization of passenger flow, passage efficiency, and safety management. For instance, through the strategic design of pedestrian flow patterns and the implementation of automated ticketing systems, numerous contemporary metro stations have successfully optimized passenger flow management. Nevertheless, this focus on functionality frequently neglects the emotional needs of users, resulting in the perception of many metro stations as "cold" and "monotonous" environments [21]. In recent years, with the advent of user experience design principles, the emotional aspects of metro station environments have progressively garnered attention. Currently, several studies have investigated strategies to improve the emotional experience within metro stations. For instance, the introduction of natural elements or the application of soft lighting and color schemes in metro stations has been shown to effectively alleviate the psychological stress experienced by users [22]. Moreover, innovative designs, such as interactive digital displays, have been demonstrated to significantly enhance passengers' overall sense of enjoyment [23]. However, the majority of these studies remain confined to isolated case analyses and lack comprehensive and universally applicable design frameworks.

Emotional perception refers to individuals' subjective emotional responses to external stimuli within a given environment, often encompassing a range of emotional states, including pleasure, comfort, and anxiety. These emotional responses constitute a holistic evaluation of environmental stimuli, shaped by multiple factors, including spatial layout, visual elements, auditory cues, and lighting conditions [24]. Existing research predominantly employs survey-based methodologies to investigate emotional perception, and this research paradigm has become relatively well-established, with instruments such as the UCLA-20 Loneliness Scale and the Psychological Wellbeing Scale being extensively utilized in the literature [25]. In recent years, frameworks such as the Circumplex Model of Affect and affective computing models have gained widespread application in emotion research, offering a robust theoretical foundation for the quantitative analysis of emotional responses [26]. With the advancement of affective computing technologies, research on emotional perception in public spaces has increasingly transitioned from qualitative

descriptions to quantitative analysis. Artificial intelligence-based emotional analysis techniques, including facial expression recognition, voice emotion analysis, and physiological data measurement, have furnished powerful tools for investigating emotional dynamics in public space design. These methodologies have facilitated the efficient acquisition and analysis of emotional data, thereby providing scientific evidence for the emotional optimization of designs across various spatial typologies [27,28].

Public spaces serve as critical venues for human social interactions, with their design exerting a direct influence on users' emotional experiences. Research indicates that positive emotional perceptions significantly enhance the appeal and usability of public spaces. For instance, in open environments like urban squares and parks, designs that prioritize emotional experiences are often more favorably received by users [29]. Conversely, enclosed spaces like airport lounges and metro station concourses frequently disregard emotional considerations in favor of meeting stringent functional demands [30]. Nevertheless, existing studies have substantiated that enhancing emotional experiences within indoor public spaces can markedly alleviate user stress and anxiety, while simultaneously fostering comfort and a sense of belonging [31]. Emotional perception within public spaces extends beyond its impact on psychological well-being to play a pivotal role in shaping behavioral decision making. Emotionally positive environments foster social interactions, prolong dwell times, and stimulate consumer behavior, whereas negative emotional responses can prompt swift exits or even deter future re-entry [32]. This relationship provides essential insights for emotional design, emphasizing the optimization of environmental elements to elicit improved emotional responses and, consequently, guide user behavior.

Affective computing, an interdisciplinary domain dedicated to the study of human emotional perception and expression, has experienced rapid advancements since its introduction by Picard [33]. By leveraging the analysis of facial expressions, vocal characteristics, physiological signals, and textual emotional information, affective computing offers a diverse array of techniques for the quantitative assessment of emotional states [34]. With continuous technological advancements, research methodologies in affective computing have evolved correspondingly. For instance, long short-term memory (LSTM) networks have demonstrated remarkable efficacy in vocal emotion analysis, and natural language processing (NLP) has significantly enhanced the accuracy of textual emotion analysis. These advancements have substantially increased the efficiency and precision of acquiring and processing emotional data [35,36]. In recent years, affective computing technologies have found increasing application in spatial analysis, offering robust scientific foundations for the emotional optimization of public space design. For example, emotional maps enable the visualization of emotional distributions across various areas, uncovering the latent influence of environmental factors on users' emotional responses [37]. Furthermore, integrating affective analysis with virtual reality (VR) technology facilitates the early-stage evaluation of design schemes through users' emotional responses, thereby enabling the real-time optimization of spatial configurations [38]. The convergence of affective computing and spatial analysis necessitates interdisciplinary collaboration across fields such as architecture, psychology, and computer science. Such interdisciplinary endeavors advance the quantitative investigation of the interplay between emotional responses and environmental factors. For instance, semantic segmentation techniques can extract spatial visual features—including color, lighting, and material—and, when integrated with affective computing models, assess the impact of visual elements on emotional responses [39]. Theoretical frameworks from environmental psychology offer profound insights into the interpretation of emotional data [40]. Incorporating social media data further broadens the scope of research on public emotional feedback [41].

These studies suggest that metro stations, as dynamic environments, are influenced by various factors, including crowd density and time of day, which can significantly impact both the visual environment and users' emotional perceptions. However, existing research predominantly centers on emotional analysis within static environments, with relatively limited investigation into emotional data acquisition and analytical methods in dynamic, complex settings. Concurrently, while metro station designs prioritize functional requirements, they frequently neglect the optimization of emotional experiences. The key challenge lies in striking a balance between optimizing operational efficiency and providing user comfort, fulfilling passengers' practical needs while simultaneously enhancing their emotional satisfaction. This issue represents a critical challenge that must be addressed in the design of metro stations. Future research must continue to explore innovative ways in which spatial design can enhance emotional perception. As technological advancements and evolving societal demands continue to shape the landscape, methods for optimizing users' emotional perceptions through design will evolve, providing a wide range of possibilities for future design.

2. Methodology

2.1. Workflow

As shown in Figure 1, the technical approach employed in this study can be delineated into four key steps: (1) collection of on-site photographs representing the scene; (2) extraction of environmental features using semantic segmentation techniques; (3) acquisition of emotional perception data from images extracted from video footage through computer vision methodologies; (4) visualization of the obtained data and subsequent correlation analysis.

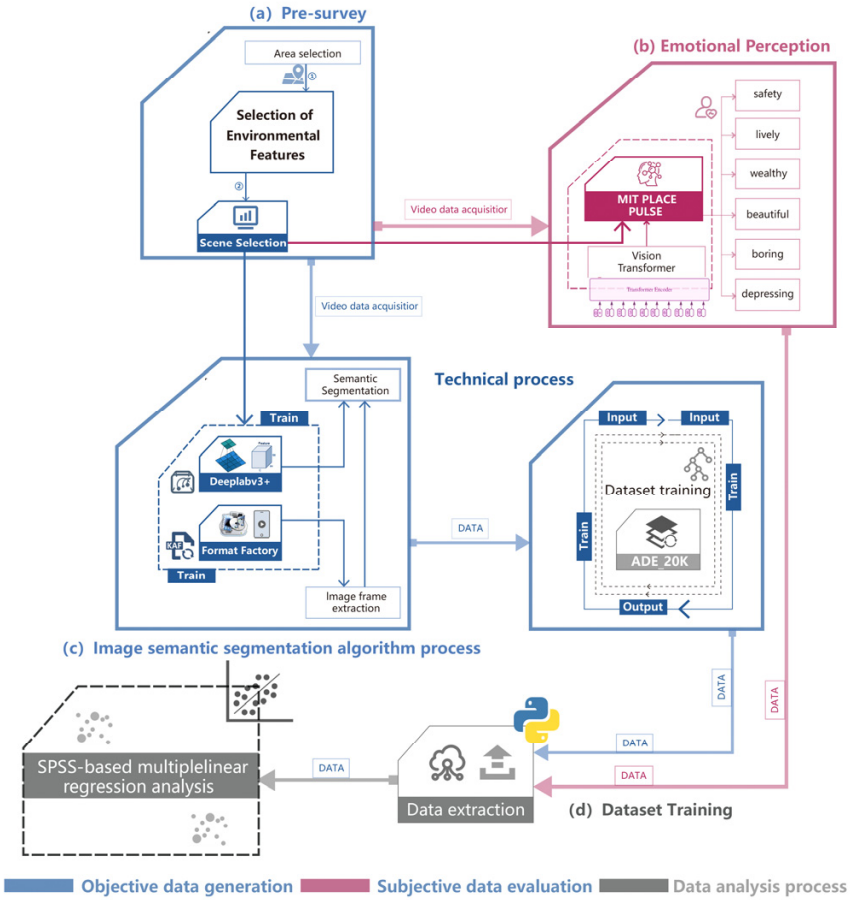


Figure 1. Workflow chart.

As shown in Figure 2, data collection was carried out through photographic capture, with the images taken in November 2024. The selected sites comprise 70 metro stations in Harbin. The photographic scenes were chosen within the spatial environment of the metro stations, with each of the 70 stations photographed individually. Each station was subdivided into five distinct sections for individual photography: entrance stairs, corridors, station halls, station stairs, and platforms.

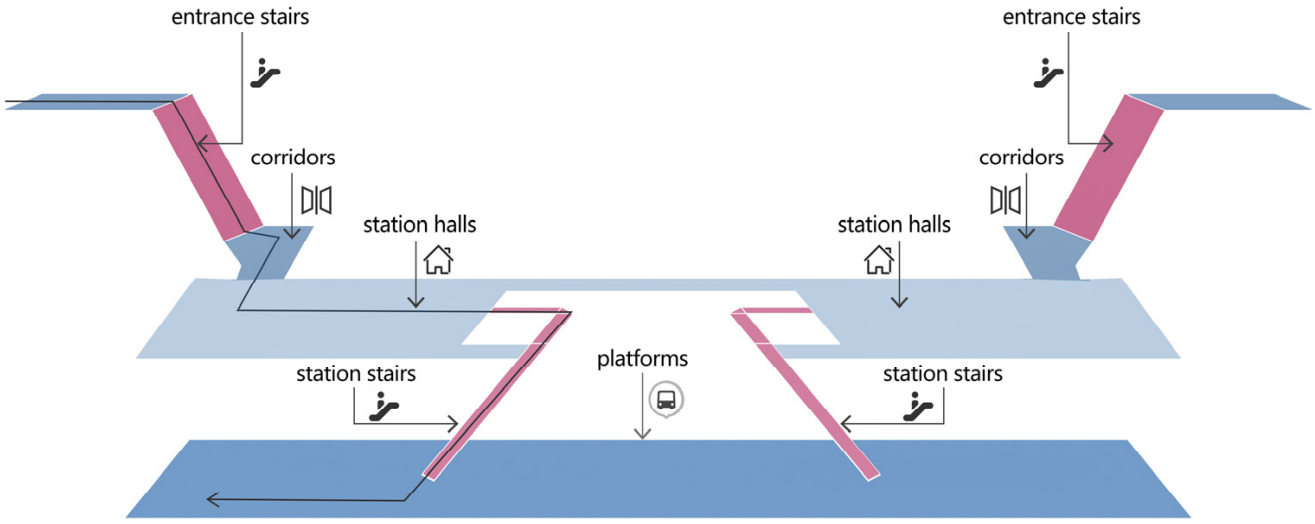


Figure 2. Schematic diagram of the space inside the metro station.

2.2. Research Area

The survey for this experiment was conducted across all stations of the Harbin Metro network. The Harbin Metro is a key urban rail transit system in Harbin, Heilongjiang Province, China, and it officially commenced operations on 26 September 2013. It is the northernmost metro system in China. The construction and operation of the system play a crucial role in mitigating urban traffic congestion, enhancing travel conditions, and fostering urban development. As shown in Figure 3, the Harbin Metro operates multiple lines, which can be broadly categorized into three main segments:

Line 1: Running in a northeast–southwest direction, connecting Harbin East Station with Hanan Station, serving as the backbone of the Harbin Metro system.

Line 2: Running north–south, passing through the city center.

Line 3: A circular line, operating in segments, with plans for future full-circle operation.

Harbin Metro currently operates 70 stations, all of which are included in this study to ensure the comprehensiveness and objectivity of the research.

This study relies on data from a single city, which may restrict the generalizability of the findings. Given that the data in this study are confined to environmental images from a specific urban context, the results may not fully capture the emotional response patterns across different global or metropolitan settings. As a representative city in northern China, the findings from the Harbin metro station may serve as a valuable reference for metro station designs in cities sharing similar socio-cultural and environmental contexts. Future studies could benefit from expanding the dataset to encompass a broader range of regions, cultural contexts, and city types, thereby facilitating the validation of our findings and strengthening the external validity of the results.

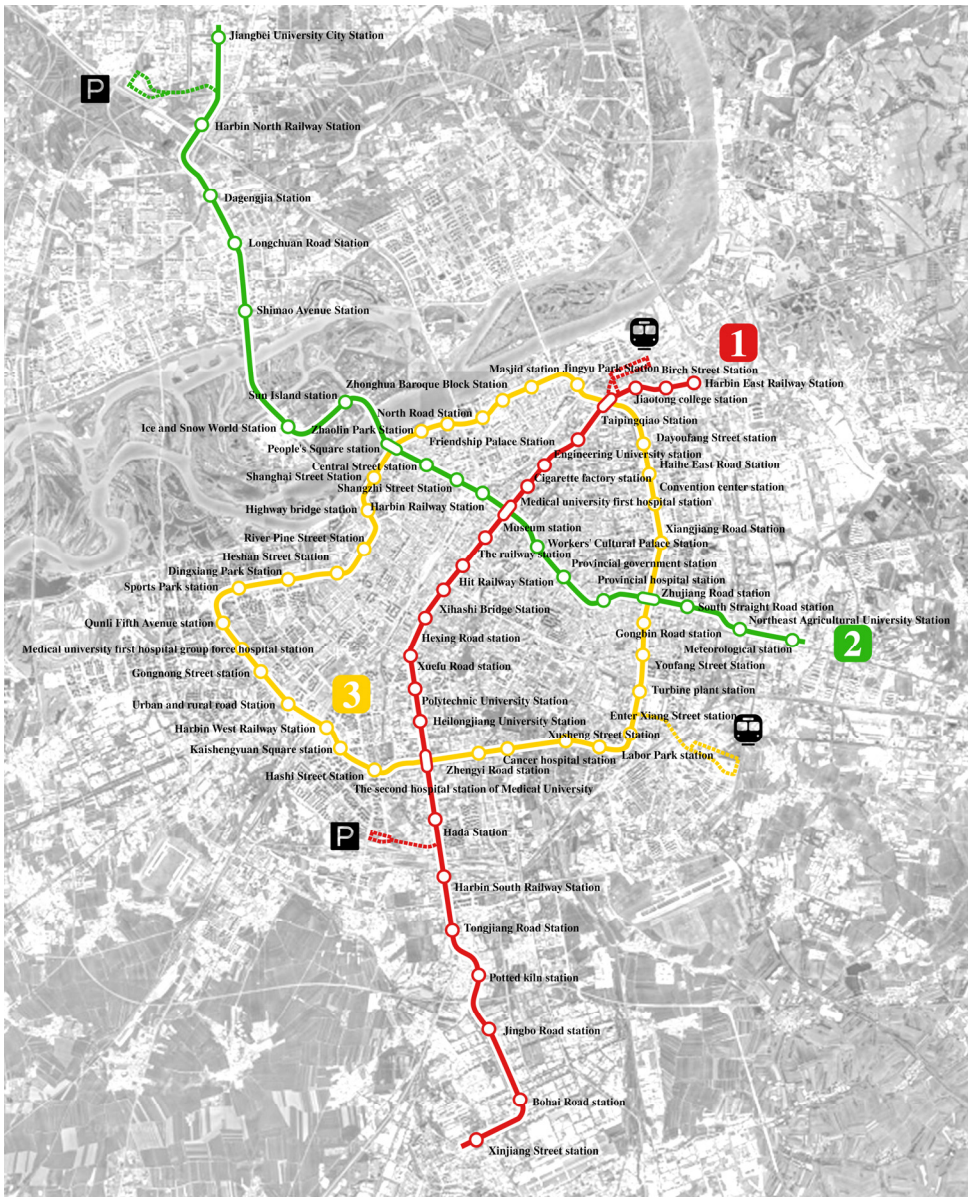


Figure 3. Harbin metro map.

2.3. Research Tools

2.3.1. Semantic Segmentation

Semantic segmentation is a fundamental task in computer vision, which aims to assign each pixel in an image to a predefined category. Unlike traditional image classification, semantic segmentation operates at the pixel level, classifying each pixel and thereby attributing semantic labels to distinct regions within the image. For instance, in a street scene image, semantic segmentation assigns labels to individual pixels, categorizing them into classes such as "road", "building", and "pedestrian". Common techniques employed in semantic segmentation include convolutional neural networks (CNNs), fully convolutional networks (FCNs), and U-Net, with the latter proving particularly effective in medical image segmentation. Semantic segmentation has found widespread applications in diverse fields, including autonomous driving, medical image analysis, and remote sensing image processing.

This study employs the DeepLabV3+ model for the semantic segmentation of video scenes. DeepLabV3+ is a state-of-the-art convolutional neural network (CNN) architecture, specifically designed to tackle complex image segmentation tasks. The model integrates

the benefits of dilated convolution and multi-scale feature extraction, enabling it to effectively capture semantic information across varying scales, thereby enhancing segmentation accuracy [42].

Regarding the dataset, this study utilizes the ADE_20K dataset as the foundation for model training and evaluation. ADE_20K is a large-scale semantic segmentation dataset containing diverse everyday scenes and object categories, making it suitable for both indoor and outdoor scene segmentation tasks. The dataset provides extensive annotation information, which enables the model to learn the relationships between various scene elements [43].

During model training, data augmentation techniques, including random cropping, rotation, and color transformations, were applied to enhance the model's generalization capabilities. The training process consisted of 120,000 iterations, utilizing the cross-entropy loss function and the Adam optimizer, with the learning rate adjusted according to the performance on the validation set. Upon the completion of training, the model achieved a mean Intersection over Union (mIoU) score of 0.51 on the test set, indicating strong segmentation performance.

2.3.2. Emotional Perception

This study leverages affective computing methods to acquire the data necessary for emotional perception analysis. Affective computing refers to the domain of utilizing computational technologies to recognize, understand, express, and simulate human emotions. Its primary objective is to enable computers to perceive, process, and respond to users' emotional states, thus facilitating more intelligent and personalized interactive experiences. Affective computing has found extensive applications in diverse fields, including human–computer interaction, healthcare, education, and entertainment, where it is employed in intelligent systems that assess user emotions, enhance user experience, or deliver personalized services.

This study utilizes the MIT PLACE PULSE dataset, developed by the Massachusetts Institute of Technology, which comprises a substantial collection of outdoor scene images annotated with emotional perception data. Each image is associated with ratings for various emotional dimensions, such as pleasure, activation, and subjective sense of safety, designed to assist researchers in understanding the influence of the environment on emotional responses [44]. According to environmental psychology theory, the physical attributes of the environment, such as spatial layout, lighting, color, and noise, can significantly impact individuals' emotional states. The MIT PLACE PULSE dataset, which gathers emotional ratings for various scenes, allows for the correlation of these emotional responses with the visual characteristics of the environment—such as landscapes, buildings, roads, and greenery—thereby offering valuable insights into how environmental perception influences emotional reactions. This approach provides a framework for investigating how environmental perception shapes emotional reactions. For instance, brightly lit, open spaces are often associated with higher levels of pleasure and activation, whereas dimly lit and crowded environments tend to evoke increased anxiety and feelings of insecurity.

Building upon this, the study employs the Vision Transformer (ViT) model for computer vision tasks. ViT is a deep learning model based on the Transformer architecture, particularly proficient at handling image data and excelling in capturing long-range dependencies and global context. Compared to traditional convolutional neural networks, ViT enhances the capture of fine-grained features in images by dividing them into smaller patches and applying self-attention mechanisms.

This study employs the MIT PLACE PULSE dataset to train the Vision Transformer (ViT) model for extracting emotional perception features from images. The MIT PLACE

PULSE dataset comprises a large collection of urban landscape images associated with human emotional perception, annotated with diverse emotional responses to offer data support for emotion perception analysis.

To ensure the model's effectiveness, this study initially performed comprehensive preprocessing on the dataset. This involved normalizing the images to standardize their color and brightness, thereby mitigating the influence of varying image acquisition conditions on the model. Concurrently, data augmentation techniques were employed to increase the diversity of the training data, thereby improving the model's robustness and generalization capacity. This process allowed the model to better adapt to emotional perception tasks across various scenes while reducing the risk of overfitting.

This study adopted a transfer learning strategy, leveraging a ViT model pre-trained on large-scale datasets as a feature extractor to capture visual features with emotional expression capability. Transfer learning significantly reduces training time and enhances the model's performance on smaller datasets. Specifically, initial feature representations were obtained from ViT models pre-trained on large-scale visual datasets, such as ImageNet, and the model was fine-tuned to optimize its performance for the emotional perception task. During the training process, hyperparameters such as a learning rate of 0.01, batch size of 8, and the AdamW optimizer were meticulously adjusted to optimize training efficiency and achieve faster convergence and higher accuracy. Upon the completion of training and validation, the emotional perception data output by the model were subjected to quantitative analysis. By performing statistical and visual analysis of the emotional features extracted from the images, this study aims to uncover which spatial features are most likely to induce comfort or pleasure in users.

2.4. Data Extraction

As shown in Figure 4, the experiment selected and captured images from 70 metro stations, covering five distinct functional spaces. Semantic segmentation and emotional perception data extraction were performed on the images from each scene, yielding 11 types of physical space features and 6 types of emotional perception features.

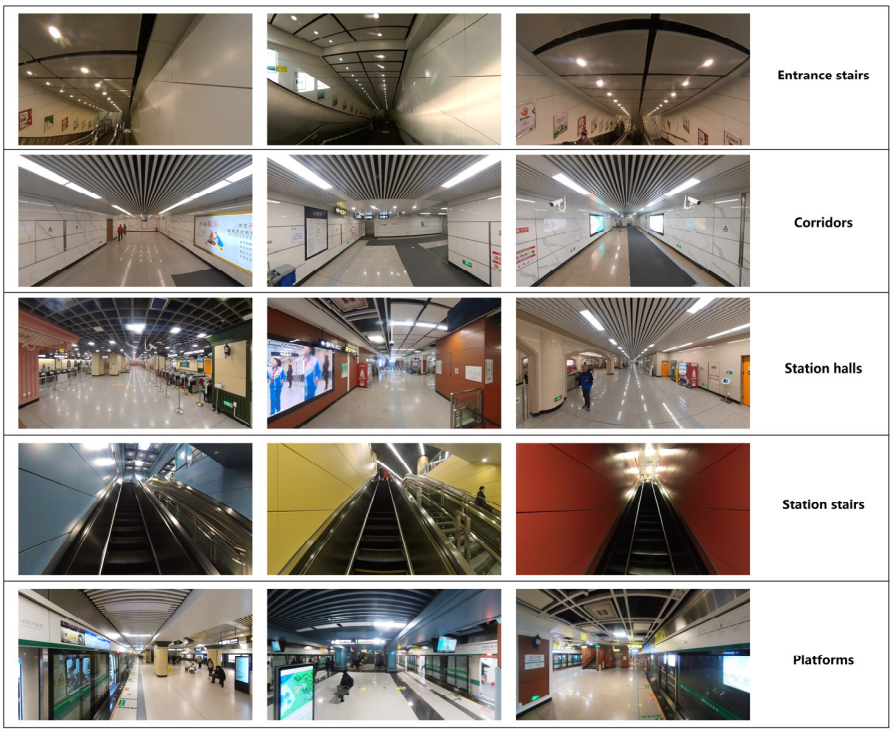


Figure 4. Example of image recognition.

3. Results

3.1. Descriptive Statistics and Correlation

Through the analysis of the captured images, a total of 17,481 data points were extracted, with 3005 data points from entrance stairs, 2723 from corridors, 3208 from the station hall, 2291 from station stairs, and 6254 from platforms. SPSS was employed for correlation analysis in this study, and the report presents descriptive statistics and Pearson correlation analysis results for these variables. All parameters showed significance levels below 0.05, indicating that the model's predictions for the dependent variables are statistically significant. Furthermore, all parameters exhibited collinearity values below 10, suggesting low linear correlations between the independent variables, which ensured that the estimation of the regression coefficients was not significantly affected

3.2. Selection of Environmental Characteristics and Perception Parameters

This study, with the aim of assessing various emotional perception scores for different spaces within the metro station, divided the station into five functional zones: entrance stairs, corridors, station hall, station stairs, and platforms. Additionally, based on common environmental features in metro station scenarios, 11 recognizable environmental attributes were selected, including wall, floor, ceiling, road, person, door, table, plant, seat, counter, and stairway. Furthermore, based on environmental psychology and the scope of the MIT PLACE PULSE dataset, six emotional perception scores were selected: safety score, lively score, beautiful score, boring score, depressing score, and wealthy score.

3.3. Parameters of the Correlation Model

Figure 5 illustrates the correlation between the different variables analyzed. These results indicate that emotional perception varies significantly across different scenes within the metro station, while the influence of distinct physical environmental features is relatively minor. The study found that the entrance stairs show a moderate negative correlation with lively perception and a negative correlation with depression perception; the corridor section demonstrates a positive correlation with safety perception scores; the platform section has minimal impact on emotional perception scores; the station stairs exhibit a negative correlation with lively perception; and the platform shows a negative correlation with safety and beauty perceptions, but a positive correlation with lively perception.

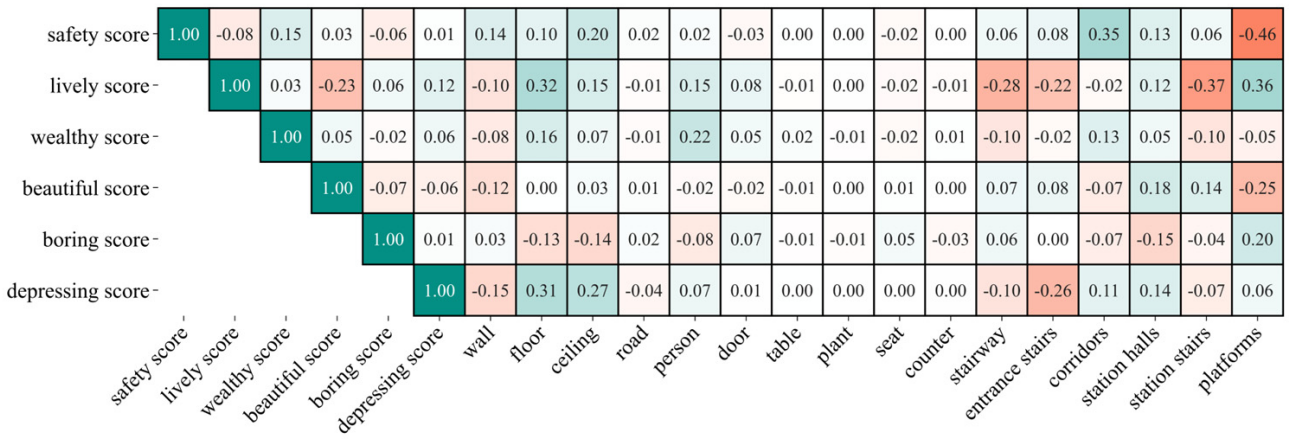


Figure 5. Correlation between emotional perception scores and metro station spaces.

In the correlation analysis, significance levels refer to the threshold used to assess whether the observed research findings are statistically significant. In simple terms, they serve to determine whether the observed correlation is attributable to random fluctuations

or reflects a genuine relationship between variables. The significance level indicates the permissible probability of error when drawing inferences from the results. For example, by setting the significance level at 0.05, if the *p*-value falls below this threshold, we can be 95% confident that the observed correlation is not a product of chance but rather reflects a true relationship between the variables. If the *p*-value is greater than or equal to the significance level, the null hypothesis cannot be rejected, suggesting that the observed correlation between the variables may be a result of random chance. Typically, the null hypothesis asserts that no correlation exists between the two variables, while the alternative hypothesis posits a correlation, with 0.05 being the most widely adopted threshold. The significance of all these individual data points was less than 0.01, suggesting that the values are statistically significant in predicting the dependent variables. In line with previous research, it is typically assumed that the influence of individual environmental features on perception scores in a scene is significant. This study deviates from this approach by conducting a correlation analysis of the five emotional perception scores. In addition to discussing the impact of various environmental features on perception scores, this study also considers the interrelations among different perception scores. The analysis reveals a moderate negative correlation between beauty perception and lively perception.

4. Discussion

4.1. Entrance Stair Space and Station Stair Space

The data obtained in this study indicate a moderate negative correlation between the entry–exit stairways and both vitality and depression perception scores, with the station stairs also exhibiting a similar negative correlation with lively perception scores. Given the substantial similarities between these two types of stairways, this study will discuss them collectively. The presence of stairs in metro stations may increase the physical burden on pedestrians. Climbing stairs requires a certain level of physical strength and endurance, particularly when carrying heavy items or during peak commuting periods. This additional physical exertion may induce fatigue, reducing positive emotional perceptions of the environment [45]. Furthermore, the passage pressure and potential safety hazards associated with stairs may induce feelings of anxiety and unease in pedestrians, thereby lowering the lively perception scores of the environment [46]. The design of stairs in metro stations can impact pedestrian flow efficiency and spatial utilization behavior. The presence of stairs may cause pedestrians to slow down, creating bottlenecks, especially during peak hours when pedestrian traffic is dense. This phenomenon may lead to congestion and delays, which can amplify feelings of frustration towards the environment [47].

Existing studies suggest that relevant issues can be addressed by shaping the environmental atmosphere. The addition of greenery, decorative lighting, or public art installations near stairways can visually soften the rigidity of the stair structure, creating a more appealing spatial atmosphere, which, in turn, enhances the overall lively perception scores of the environment [48]. Such design approaches not only enhance the visual appeal of the environment but also, through positive psychological cues, indirectly reduce pedestrians' feelings of frustration.

It is noteworthy that different social groups may perceive the stairway environment in metro stations differently. For instance, younger individuals may be more inclined to view stairways as a daily exercise opportunity, thereby enhancing their lively perception of the environment. In contrast, older adults or passengers with large luggage—such as those with mobility limitations—may be more susceptible to the negative effects of stairways [49]. Therefore, in the design of metro station entrances and exits, it is essential to fully consider the unique needs of different users and to employ diverse design strategies to accommodate the varied travel demands.

4.2. Corridor Space

The findings of this study reveal a positive correlation between metro station corridor spaces and safety perception scores. As critical transit areas for passengers, corridor spaces in metro stations are significantly influenced by spatial elements such as width, height, lighting, materials, and wayfinding systems. Spacious corridors help reduce the sense of crowding and mitigate the safety hazards caused by high pedestrian density, thereby enhancing passengers' psychological safety perception [50]. Proper corridor height and visual openness provide passengers with a sense of comfort and ease in observing their surroundings, reducing the oppressive and potentially threatening sensations associated with narrow or low spaces [51]. Additionally, adequate lighting design and light distribution eliminate shadows and visual blind spots, fostering a heightened sense of security among passengers [52]. The choice of materials for floors and walls is also crucial. Slip-resistant, sturdy flooring and durable, easy-to-clean wall surfaces enhance the physical safety of the corridor, which indirectly bolsters psychological safety perception [53].

The layout and design of corridor spaces in metro stations are directly linked to passenger flow distribution and mobility, thereby influencing safety perception scores. During peak hours, the width and segmentation of corridors can effectively alleviate congestion, reduce the likelihood of interpersonal friction and conflicts, and enhance passengers' psychological safety perception [54]. Moreover, well-planned circulation designs, such as the use of clear signage and wayfinding systems to guide passenger flow, can prevent crowd stagnation or disorientation within corridors, thereby mitigating anxiety caused by uncertainty [55].

4.3. Platform Space

The findings of this study indicate a negative correlation between platform spaces in metro stations and both safety perception scores and beauty perception scores, while exhibiting a positive correlation with lively perception scores.

The negative correlation between platform spaces and safety perception may stem from their openness and expansive visibility. In metro station environments, open platform spaces may evoke a sense of exposure, as the lack of enclosed and protective surroundings can induce feelings of insecurity [56]. This psychological mechanism can be explained through the "prospect-refuge theory" in environmental psychology, which posits that humans are naturally inclined to feel secure in environments that offer both refuge and good visibility [57]. However, overly open and densely populated metro station platforms may lack evident refuges, leading to a diminished sense of security among passengers [58]. Effective solutions may include the strategic zoning of platforms, utilizing lighting and color to guide passengers' visual focus and create a welcoming and protective environment.

The negative correlation between platform spaces and beauty perception may stem from the trade-off between functionality and esthetic design. Metro station platforms primarily serve transportation functions, emphasizing practicality and durability, often at the expense of esthetic considerations. In terms of material selection, commonly used materials such as concrete, metal, and glass, while durable, can appear visually monotonous. Spatial designs that lack decorative elements or visual focal points are prone to causing visual fatigue, thereby diminishing the esthetic appeal of the environment [59]. Strategies to enhance beauty perception may include the incorporation of artistic decorations, vibrant wall designs, and natural elements such as greenery and water features. These elements can soften the industrialized characteristics of the space, creating a more welcoming and humanized environment. Additionally, flexible lighting designs and dynamic display screens can further enhance visual appeal and enrich passengers' sensory experiences.

The positive correlation between platform spaces and lively perception is closely associated with the dynamic qualities and interpersonal interactions fostered by open environments. Open platform spaces are often characterized by a higher capacity for pedestrian flow and greater passenger movement, thereby amplifying the perception of vitality within the environment. Passengers in open spaces can more easily observe the behaviors and activities of others, fostering a sense of group dynamics. This visual dynamism, coupled with the ebb and flow of pedestrian traffic, can effectively enhance the lively perception of the environment [60]. The density of crowds and the presence of commercial activities on platforms also influence lively perception. If platform space design accommodates diverse commercial facilities such as cafés, convenience stores, and interactive displays, it can effectively stimulate passenger interest and engagement. This is particularly impactful in busy areas like metro interchange hubs, where such configurations contribute to creating multifunctional and multilayered vibrant spaces.

In summary, metro station platform spaces exhibit a significant dual effect in shaping passengers' emotional perceptions. Enhancing safety perception requires rational spatial layouts and functional facilities, while improving beauty perception necessitates a focus on esthetic design and environmental decoration. As for enhancing lively perception, it requires a synergy between spatial openness and functional diversity.

4.4. Physical Space Features

The findings of this study indicate that the various physical spatial characteristics within a metro station exert minimal influence on users' emotional perception ratings. This outcome may be attributed to the relative homogenization of physical spaces within a metro station. Although functional zoning has been intentionally incorporated within metro stations, the interior spatial design exhibits a trend toward homogenization. This homogenization is reflected in the absence of significant variation in the spatial form, color, materials, and furniture design styles across different areas within metro stations, as well as between various metro stations. Consequently, this leads to a lack of distinctiveness and individuality in the various spaces within a metro station. The scene images simulate a human perspective, where from a perceptual standpoint, the proportion of different physical spatial characteristics in the field of view remains relatively constant as users navigate through various sections of the metro station. As a result, the various physical spatial characteristics within the metro station have a minimal effect on users' emotional perception ratings.

The occurrence of this phenomenon can be primarily attributed to the interplay of multiple factors, including the demands for standardization and cost control, considerations of functionality and safety, convenience in construction and maintenance, as well as time and resource constraints. These factors, while pursuing efficiency and consistency, often come at the expense of the uniqueness and individualized expression of spatial design. Standardized design has led to the adoption of uniform design specifications and elements across multiple metro stations, ensuring overall consistency. This approach contributes to the establishment of a cohesive brand image, providing passengers with a sense of familiarity and recognizability across stations. Simultaneously, standardized design significantly reduces construction and operational costs. By standardizing the procurement of materials, furniture, and decorations, economies of scale can be achieved, lowering procurement costs and simplifying inventory management. However, standardization often results in homogenized design, sacrificing uniqueness and esthetic appeal [61,62]. The primary function of metro stations is to efficiently accommodate and direct the flow of large numbers of passengers. As a result, strict functional requirements are placed on aspects such as spatial layout, circulation design, and signage systems. These functional demands necessitate designs that

are highly practical and consistent to ensure passengers can swiftly and conveniently reach their destinations, minimizing congestion and confusion. Consequently, the heightened emphasis on functionality and safety steers design towards standardization and practicality, thereby reducing the space for personalized design elements [63]. Standardized design in metro stations also facilitates post-construction maintenance and management. The use of uniform materials and equipment enables regular inspection, maintenance, and replacement, reducing both maintenance costs and complexity. However, this often implies a conservative and repetitive approach to design, limiting innovation and diverse design expressions, which exacerbates the phenomenon of spatial homogenization [64].

To avoid the homogenization of metro station designs, local cultural and distinctive elements can be integrated within the framework of standardization, employing modular and flexible design solutions that enable each station to reflect its unique geographical and social context. Diverse color schemes, materials, and lighting designs can be utilized to create visual differentiation, while adaptable spatial configurations are introduced to accommodate varying functional needs. Encouraging designers to innovate and incorporate artistic installations and interactive features enhances the personalized experience of the space. Additionally, within the constraints of cost and time, design standards can be flexibly adjusted to accommodate uniqueness. These strategies, while maintaining a strong focus on functionality and safety, imbue metro stations with unique visual and experiential qualities, thereby effectively preventing the phenomenon of homogenization.

4.5. Limitations and Future Research Directions

This study utilizes computer vision technology to analyze scenes and assigns perceptual ratings to the scene images based on the emotional perception dataset. The findings indicate that different functional spaces within the metro station hall result in significant variations in emotional perception ratings, while the influence of different physical environmental characteristics on users' emotional perception ratings is relatively minor. Existing related studies have also analyzed user experiences from different perspectives, such as recording and analyzing pedestrian movement trajectories, and assessing the impact of objects in the scene on pedestrian activity based on the prioritization of these movements. This research has demonstrated that the configuration of street furniture and vendor stalls in functional areas significantly influences pedestrian movement comfort, which supports the findings of the present study from an alternative perspective [65]. In light of the methodology employed in this study and corroborated by other relevant literature, we acknowledge the following limitations in this research:

(1) The image data used in this study were collected within a single city. While these data represent the emotional perception characteristics of the metro station spaces within a specific region, they do not fully capture the characteristics of metro stations in other regions or forms. Future research could incorporate comparative studies across different regions to enhance the reliability of the findings.
(2) The emotional perception scores are limited by the constraints of the deep learning dataset, being categorized into only six dimensions: safety score, lively score, beautiful score, boring score, depressing score, and wealthy score. Future studies could explore a broader range of behavioral dimensions as models advance and datasets are further optimized.
(3) The image data for this study were collected in China, where metro construction exhibits distinct characteristics that differ from other countries, reflecting a significant degree of local influence. For instance, the rapid expansion of China's metro system has enabled many cities to develop extensive metro networks within a short time frame to address the transportation demands driven by rapid urbanization, poten-

tially contributing to the homogenization of metro stations. Additionally, China's large population results in higher per capita passenger flow within metro stations. These limitations may give rise to variations in design and research methodologies. Future research could incorporate data from other countries to facilitate a more comprehensive analysis.

5. Conclusions

This study, based on the correlation between metro station spaces and emotional perception scores, reveals that different functional spaces within metro stations exhibit significant variations in their impact on users' emotional perception scores, whereas the influence of distinct physical space features is relatively minor. Different functional spaces in metro stations exert varying degrees of influence on safety perception scores, lively perception scores, beauty perception scores, and depression perception scores. The stair spaces at the entrances and exits of a metro station exhibit a negative correlation with both lively perception and depression perception scores, while the internal stair spaces also display a negative correlation with lively perception scores. The passage spaces within a metro station demonstrate a positive correlation with the safety perception score. The platform spaces within a metro station are negatively correlated with both safety perception and beauty perception scores, while they exhibit a positive correlation with lively perception scores. Consequently, optimizing the environmental design of various spaces within a metro station can significantly enhance passengers' emotional perception experiences. Specifically, for stair spaces, cultivating a vibrant atmosphere can enhance lively perception scores and reduce depression perception scores. In the passage space, implementing flow-diverting designs to alleviate congestion, while utilizing clear guiding systems to direct pedestrian movement, will effectively enhance safety perception scores. In the layout of platform spaces, strategic zoning, coupled with lighting and color to guide passengers' visual focus, should be employed to create a warm, protective environment, thereby enhancing safety perception scores. Introducing artistic decorations, vibrant wall designs, and natural elements within platform spaces can significantly enhance beauty perception scores. Furthermore, incorporating diverse commercial facilities on the platform to create a dynamic, layered vitality scene will contribute to improving lively perception scores. Future research could focus on incorporating subjective user evaluations to achieve a more comprehensive comparative analysis. Moreover, identifying which functional spaces influence users' emotional perception scores is crucial for advancing mental health promotion, stress alleviation, and emotional optimization. This study offers valuable insights and practical implications for the future design of metro station spaces, serving as a reference for future researchers.

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