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Emotional Responses to Spatial Design in a Regeneration Project: A Study Using Virtual Reality and Galvanic Skin Response Methodology

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Abstract

The exploration of emotional responses to spatial design within the context of urban regeneration is a central concern for both researchers and designers. Notably, there exists a current gap in considering emotions in urban regeneration projects. Moreover, existing methods for identifying people's emotional reactions within spatial environments primarily rely on self-reporting, which has significant limitations and heavily depends on participants' subjective expressions. As a result, it becomes essential to collect and analyze participants' physiological data using objective measures. This study introduces a systematic approach to acquire unbiased data concerning people's emotional responses to spatial design. By employing Virtual Reality and Galvanic Skin Response techniques, this proposed method presents a structured framework that enables precise emotional insights from users before finalizing the design.

Keywords

Virtual Reality, Galvanic Skin Response, Spatial Design, Emotional Responses, Research Method, Urban Regeneration

1. Introduction

Urban regeneration encompasses a comprehensive and cohesive approach aimed at addressing urban challenges while striving for lasting improvements in the economic, social, and environmental aspects of urban areas (Roberts, 2000). This strategic concept underscores the importance of maintaining the continuity of existing urban spaces and facilities, as well as preserving current buildings and environments to align with the demands of urban development (Paddison, 1993). One of the primary goals of urban regeneration is to enhance the overall quality of life for residents in the vicinity (Ng, Kam, & Pong, 2005). Central to the success of any urban regeneration initiative is spatial design, which holds the potential to significantly influence the well-being of individuals living or working within the area (Inroy, 2000). Spatial design encompasses the arrangement and organization of physical space, which can impact how people interact with their surroundings (Lau, Gou, & Liu, 2014). In regeneration projects, spatial design plays a pivotal role in shaping the identity and character of the area (Aelbrecht & Stevens, 2019). Furthermore, it has the capacity to attract new businesses, residents, and visitors, while fostering social cohesion among the existing population (Aelbrecht & Stevens, 2019).

In the era of a Human-Centered Design driven industry, design is increasingly focused on addressing higher-level human needs, infusing architectural spaces with heightened emotional significance (Zhang & Dong, 2009). Meeting people's demands has emerged as a pivotal aspect of design research, particularly within its emotional dimensions (Zhan et al., 2021). Architectural spaces serve functional purposes for daily work and life and carry profound emotional connotations. As Patrick Geddes (1915) stated, "a city is more than a place in space, it is a drama in time", indicating that a city is primarily an emotional experience. Thus, the contemporary design seeks to offer people an advanced experience where emotion is a pervasive quality that shapes the experience (Forlizzi, Disalvo, & Hanington, 2003).

It is noteworthy that there has been limited scholarly attention directed towards the exploration of human emotions within the context of urban regeneration thinking, policy, and practice (Murray & Landry, 2020). Consequently, many urban regeneration projects, while aiming for ambitious economic growth, have succeeded commercially by offering retail and entertainment facilities. However, these projects often fall short in considering the emotional needs of individuals (Ujang & Zakariya, 2015; Guo et al. 2021). Furthermore, a significant proportion of current methods employed to obtain people's feedbacks on spatial design rely on self-reported techniques such as interviews and questionnaires (Abbasi, Alalouch, & Bramley, 2016; Peters, 2017; Zhu, Huang, & Hu, 2022). While these methods do achieve a certain level of effectiveness, they have noteworthy limitations and rely heavily on the subjective expressions of participants (Taherdoost, 2022). As a result, there emerges a compelling need to gather and analyze participants' physiological data through objective measures.

In order to address this gap, the study aims to present a systematic method for detecting unbiased data concerning human emotional responses to spatial designs. To achieve this goal, the study employs immersive Virtual Reality (VR) and Galvanic Skin Response (GSR) technology to quantitatively measure the influence of spatial design on the human emotion. Additionally, user self-reporting is incorporated, enabling the collection of user feedback prior to finalizing the design.

2. Literature Review

Emotional response is the spectrum of feelings an individual may encounter in response to various stimuli (Royet et al., 2000). Within spatial design, this concept pertains to the range of feelings and reactions that are provoked by the physical and aesthetic elements of a given space. These responses may be immediate and instinctive, or they may evolve gradually as an individual reflects on their experiences within the space (Shemesh et al., 2017). Emotional responses can manifest externally, observable through facial expressions, body language, and actions, or they might remain internal, unapparent in any physical manner (Kana & Travers, 2012). For designers and planners, comprehending these responses is essential to create environments that satisfy functional requirements while also fostering well-being and enriching life quality for occupants.

VR is a technology that enables individuals to completely immerse themselves in simulated environments using a head-mounted display or other sensory devices (Coban, Bolat, & Goksu, 2022). This innovation offers a fully interactive, three-dimensional experience, faithfully reproducing the sights and sensations of real-world spaces. Within the realm of spatial design research, VR facilitates the exploration of diverse design scenarios by participants, granting researchers the opportunity to meticulously observe and quantify their emotional responses within a meticulously controlled setting. The integration of VR into spatial design has an extensive history, with a multitude of studies delving into the emotional reactions of individuals within virtual spaces (Naz et al., 2017; Shemesh et al., 2022). These investigations have successfully established a clear connection between attributes of VR spaces, such as size, color, light, texture, and shape, as well as their intricate interplay, and the emotional states of humans (Agirachman et al., 2022; Shemesh et al., 2022). In essence, these factors collectively shape the human spatial experience, thereby significantly influencing human emotions.

In academic literature, methods for evaluating emotional responses can be broadly categorized into two groups: self-report techniques and machine assessment techniques (Dzedzickis et al., 2020). Self-report techniques involve subjects self-assessing their emotional states through questionnaires, interviews, and other methods that allow participants to describe their emotional experiences (Conte, 1983). However, these methods heavily rely on the subjective expression of participants, leading to potential accuracy and objectivity issues in the collected data (Taherdoost, 2022). Therefore, there is a compelling need to integrate machine assessment techniques to enhance the precision and objectivity of the data collected. Machine assessment techniques for automatic emotion recognition encompass a range of popular methods, including electroencephalography (EEG), heart rate, blood pressure, eye activity, motion analysis and GSR (Dzedzickis et al., 2020).

EEG serves as a non-invasive technique for measuring the electrical activity within the brain (Binnie & Prior, 1994). This methodology involves the placement of electrodes onto the scalp to capture the electrical signals emitted by neurons within the brain (Khalifa et al., 2012). With its notable temporal resolution, EEG has the capability to promptly identify fluctuations in brain activity, thereby facilitating real-time monitoring. This attribute proves invaluable for examining swift modifications in brain function, such as those occurring during emotional responses (Bergmann et al., 2016). Nevertheless, interpreting EEG signals proves intricate due to their complexity, particularly when endeavoring to distinguish between different emotional states. Consequently, the development of precise algorithms for detecting emotions remains a formidable challenge (Nolte et al., 2004). Moreover, EEG requires substantial expenses and necessitates sophisticated equipment, in addition to requiring specialized training for proper operation (Green et al., 1985). These factors collectively render it problematic for smaller laboratories or clinics to integrate EEG into mood detection practices.

Blood pressure refers to the pressure exerted by the blood against the walls of the arteries as the heart pumps blood throughout the body (Saghiv et al., 2020). This crucial physiological parameter serves as an indicator of the cardiovascular system's functioning. Blood pressure is an objective physiological measurement that can be recorded and quantified (Chase et al., 2004). This objectivity lends a degree of confidence to mood studies and aids in minimizing subjectivity. Continuous monitoring of blood pressure over a period of time enables researchers to potentially capture mood fluctuations as subjects progress through different phases. However, it's essential to emphasize that while blood pressure can provide insights into an individual's emotional state, it isn't a direct or consistently reliable measure of human emotions (Hansen et al., 1999). Additionally, blood pressure is influenced by various factors such as physical activity, stress, anxiety, and overall health, making it challenging to isolate the specific impact of mood on blood pressure from other potential confounding factors (Räikkönen et al., 1999).

Heart rate is the number of heart beats per minute, serves as a fundamental physiological indicator that aids in comprehending the functionality of the cardiovascular system (van Ravenswaaij-Arts et al., 1993). The interconnection between heart rate and human emotions derives from emotions' capacity to elicit alterations in the autonomic nervous system, thereby influencing heart rate (Wu et al., 2019). It is imperative to acknowledge that heart rate variability can be influenced not solely by emotional state, but also by other variables like physical activity, caffeine consumption, medications, and underlying health conditions (Tan et al., 2019). These factors must be considered when interpreting heart rate data. Additionally, it's worth noting that changes in heart rate might not manifest immediately in response to emotional stimuli (Brosschot & Thayer, 2003). A temporal gap may exist between the emergence of the emotion and the subsequent shift in heart rate, rendering the determination of the exact timing of the emotion more challenging.

Eye activity refers to the movements and changes that occur in the eyes, including eye movements, pupil dilation, and changes in the direction of gaze (Tsai et al., 2007). The exploration of eye activity, also known as eye tracking or ocular measurement, has garnered notable attention within the realms of psychology and neuroscience (Popa et al., 2015). It serves as a valuable tool for comprehending cognitive processes, visual perception, and even emotional states. Eye tracking furnishes intricate insights into the focal points of individuals, the duration of their fixation on specific regions, and alterations in the course of their gaze (Duchowski, 2002). This richness can provide insights into subtle emotional responses. Nevertheless, the configuration and calibration of eye-tracking technology can present intricacies, requiring specialized equipment and expertise (Santini, Niehorster, & Kasneci, 2019), technical problems or inaccuracies may affect the quality of the data. Moreover, there are no substantial conclusions as to whether the use of eye tracking can be reliably used for emotion recognition (Lim, Mountstephens, & Teo, 2020).

Motion analysis pertains to the study and quantification of human movement patterns (Kaza et al., 2016). This field employs diverse techniques and methodologies to capture, track, and scrutinize movement data. Motion analysis finds wide-ranging applications across disciplines such as biomechanics, exercise science, rehabilitation, and psychology, including the measurement of human emotions. However, motion analysis primarily concentrates on observable movements, gestures, and facial expressions (Colyer et al., 2018), potentially overlooking internal emotional experiences that remain unexpressed externally. This limitation could result in an incomplete comprehension of emotions. While motion analysis excels in detecting alterations in movement patterns, accurately gauging the intensity of emotional states poses challenges (Schiffenbauer, 1974). Emotion intensity is subject to fluctuations, and these nuanced changes might not be fully captured solely through motion data.

GSR is a non-invasive and objective method for measuring emotional arousal, this physiological measure gauges emotional arousal by detecting variations in skin conductance resulting from the activation of sweat glands (Dutta et al., 2022). When an individual undergoes an emotional reaction, such as excitement or stress, their skin conductance levels rise, a phenomenon that can be quantified using a GSR sensor. The GSR method exhibits remarkable sensitivity, capable of detecting even subtle shifts in skin conductance (Ayres et al., 2021). This characteristic renders it a potent tool for gauging emotional arousal, a trait increasingly employed in both research and clinical environments. Of particular note, GSR requires a reduced number of measurement electrodes, simplifying its integration into wearable devices. This allows for the real-time assessment of an individual's emotional state during routine activities (Sahoo & Sethi, 2015). The equipment essential for GSR measurements is uncomplicated and cost-effective. By utilizing commonplace and freely available components such as ADC converters and microcontrollers, measurement devices can be constructed. Moreover, GSR generates less voluminous raw data, especially during extended monitoring periods. This streamlined data collection process facilitates quicker analysis without a heavy computational burden (Bruun, 2018). However, it is important to acknowledge that the GSR signal is modulated by sympathetic activity, a process beyond conscious control (Lidberg & Wallin, 1981). It means the GSR signal conveys the intensity of the emotional response rather than the specific emotion itself.

Given below, after a thorough evaluation and consideration of various machine assessment techniques, the GSR technique has been chosen for this study to analyze people's emotional data (**Table 1**). This selection is based on several factors, including the practicality and feasibility of GSR, as well as its alignment with the emotional intensity data required for the study. Furthermore, GSR proves to be a cost-effective option, and the subsequent post-data analytical procedures are characterized by their simplicity and clarity, eliminating the need for specialized guidance. In summary, the utilization of GSR technology in conjunction with self-reporting allows for a more detailed and reliable foundation for examining and interpreting emotional states.

3. Methodology Development

The study's methodology incorporates several key components, including the utilization of virtual reality, GSR methods, and self-reporting surveys. To ensure the sample is representative of the relevant population, the selection criteria might include:

- Connection to Urban Regeneration: Participants are directly associated with urban regeneration sites or projects. This can include frequent visitors to these sites, individuals living in the community where regeneration is occurring, or stakeholders in businesses affected by the regeneration.
- Professional Involvement in Design: Including designers and academic researchers ensures that the study considers expert opinions and current design research, aiding in the development of practical and theoretically informed outcomes.
- Project Leadership Experience: Engaging project leaders provides insights into the strategic and operational challenges of urban regeneration projects,

Table 1. Characteristics of different methods.

Method characteristics	EEG	Blood pressure	Heart rate	Eye activity	Motion analysis	GSR
High accuracy	✓			✓		✓
Emotional intensity	✓					✓
Easy to analyse data		✓	✓		✓	✓
Real-time	✓	✓		✓	✓	✓
Cost-efficient		✓	✓		✓	✓

offering a comprehensive understanding of the project lifecycle.

- Governmental Perspective: Government officials can provide a regulatory and policy-making perspective, which is crucial for understanding the broader implications of urban regeneration.
- Diversity in Age: A range of ages from 21 to 50 ensures that the study captures the attitudes and perceptions of a demographically diverse group, which may vary by age.
- Health Status: Only healthy volunteers are chosen to ensure that the physical requirements of the study (such as wearing VR equipment and having GSR measurements taken) do not pose any risk to the participants.

Before the study begins, all participants would be thoroughly briefed on the purpose of the research, the procedures involved, and any ethical considerations, including their right to withdraw from the study at any time. This briefing is crucial to obtain informed consent from the participants.

The aim of this study is to compare whether the conceptual design elicits a more emotional response from the participants relative to the original design. To achieve this, two comparison projects are selected: the original spatial design of the regeneration project and a conceptual design proposal. The conceptual space design is crafted using virtual reality technology, employing software such as SketchUp and Lumion to generate a detailed 3D model. Concurrently, the original design is captured using a 360-degree camera and then converted into VR format to correspond with the scenario depicted in the conceptual design. The endeavor entails the utilization of a Raspberry Pi in conjunction with the Grove - GSR Sensor V1.2 for the purpose of acquiring GSR data.

The experiment unfolds in two phases. In the initial phase, participants are instructed to wear a VR headset and a GSR device (**Figure 1**). They are presented with a plain white space to record their emotional responses, a step designed to mitigate any potential emotional fluctuations stemming from their initial exposure to virtual reality. Subsequently, participants wear both the VR headset and GSR device while engaging with the original design, recording their emotional responses. The duration of this phase varies according to the participant's viewing speed and emotional state, concluding when emotional fluctuations have largely stabilized. The same methodology is then employed to gather emotional responses to the conceptual design (**Figure 2**). The research team takes measures to control for external factors that could influence mood changes, ensuring a quiet experimental environment to minimize data bias. In the second part of the study, subsequent to their VR experience, participants complete a brief questionnaire to convey their emotional feelings.

3. Case Study and Data

To demonstrate how the proposed methodology detect human emotion, Liverpool's Royal Albert Dock has been selected as a case study. Renowned for its distinctive architecture and integral role in a regeneration project, the Royal Albert

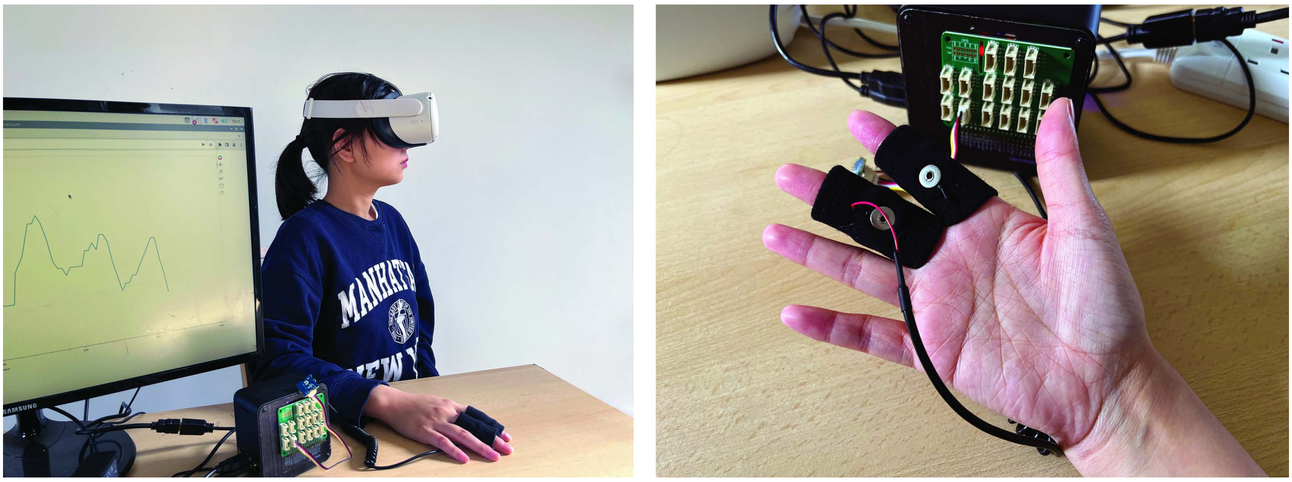

Figure 1. Participants wear both the VR headset and the GSR device.

Figure 2. Experience original designs and conceptual designs using VR technology.

Dock has stood as a landmark in Liverpool for an extended period (Zhan, Guo, & Roberts, 2023). The Maritime Museum located at Albert Dock was selected as the basis for this experiment's original design. Three indoor settings—the Albert Dock History Showroom, the Video Room, and the Exhibition Room—were captured using 360-degree cameras and subsequently transformed into VR format. These three scenes align with the three scenes in the conceptual design (**Figure 3**). The objective of this comparison was to evaluate the emotional impact of the new design by analyzing users' emotional reactions to the existing design in contrast to the conceptual design.

The findings indicate that the GSR values exhibit high inter-individual variability, implying that the physiological state of each person is not consistent and is subject to time and situational variations. Consequently, the absolute magnitude of GSR values cannot be considered as a reliable indicator of the participants' emotional state. Instead, the study focused on analyzing the fluctuating changes in GSR data to determine the emotional arousal levels of participants across different design solution. The GSR data is presented in the form of a line

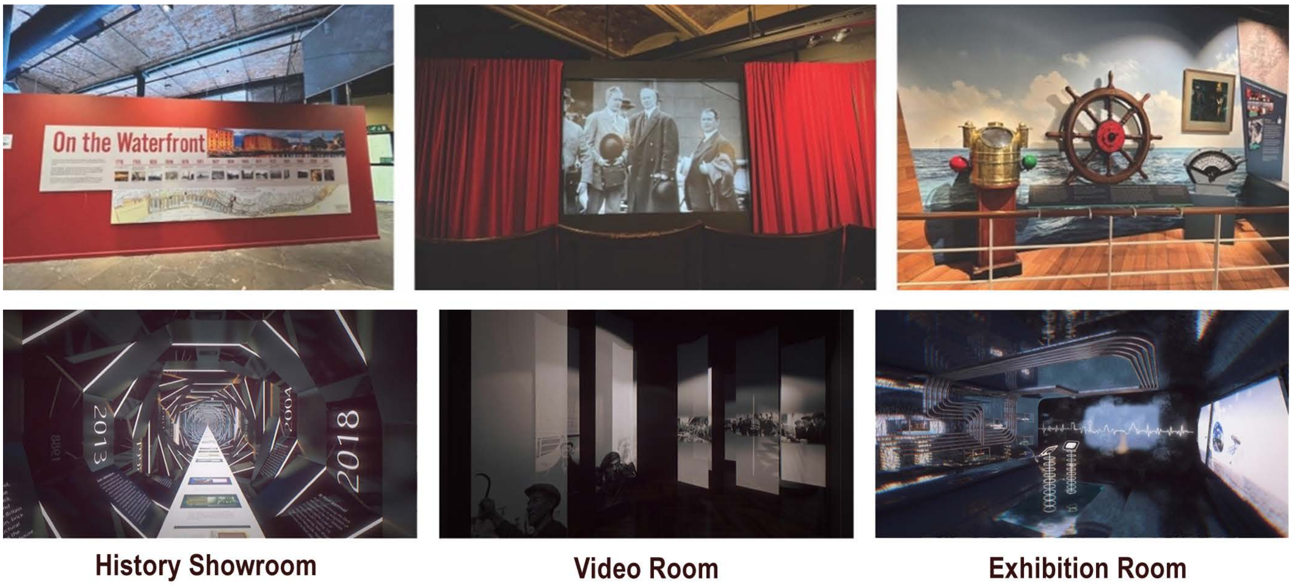

Figure 3. Comparison of existing design and conceptual design.

graph (**Figure 4**), which depicts the changes in participants' emotional arousal levels across different design scenarios. Specifically, a greater magnitude of mood swings denotes a stronger emotional response to the design solution, while lower emotional responses suggest less impact of the design scenario on the participants.

To further clarify the results of the experiment, the emotional fluctuations of participants towards the existing design and the conceptual design are analyzed. As there are multiple sets of comparison design scenarios and the primary objective of the experiment was to obtain participants' emotional responses to the overall design. To achieve this objective, the mean GSR of each participant was calculated across the different design scenarios. GSR_p can be expressed as:

$$GSR_p = \left(\sum_{s=1}^{ps} GSR_s \right) \Big/ ps$$

where p represents the participant, s represents the design scenario and ps represents number of the design scenarios. Subsequently, the emotional fluctuation rate EFR_p for the overall design was determined for each participant. It can be calculated using the following formula:

$$EFR_p = \left(\frac{\max\left(GSR_p\right) - \mu_p}{\mu_p} \right)$$

where μ_p represents the average of the GSR values within the stable mood state for each participant. Finally, the average emotional fluctuation of all participants was calculated and expressed as EV, using the following formula:

$$EV = \left(\sum_{p=1}^{np} EFR_p \right) \Big/ np$$

where np is the number of participants. The resulting EV-value for the existing

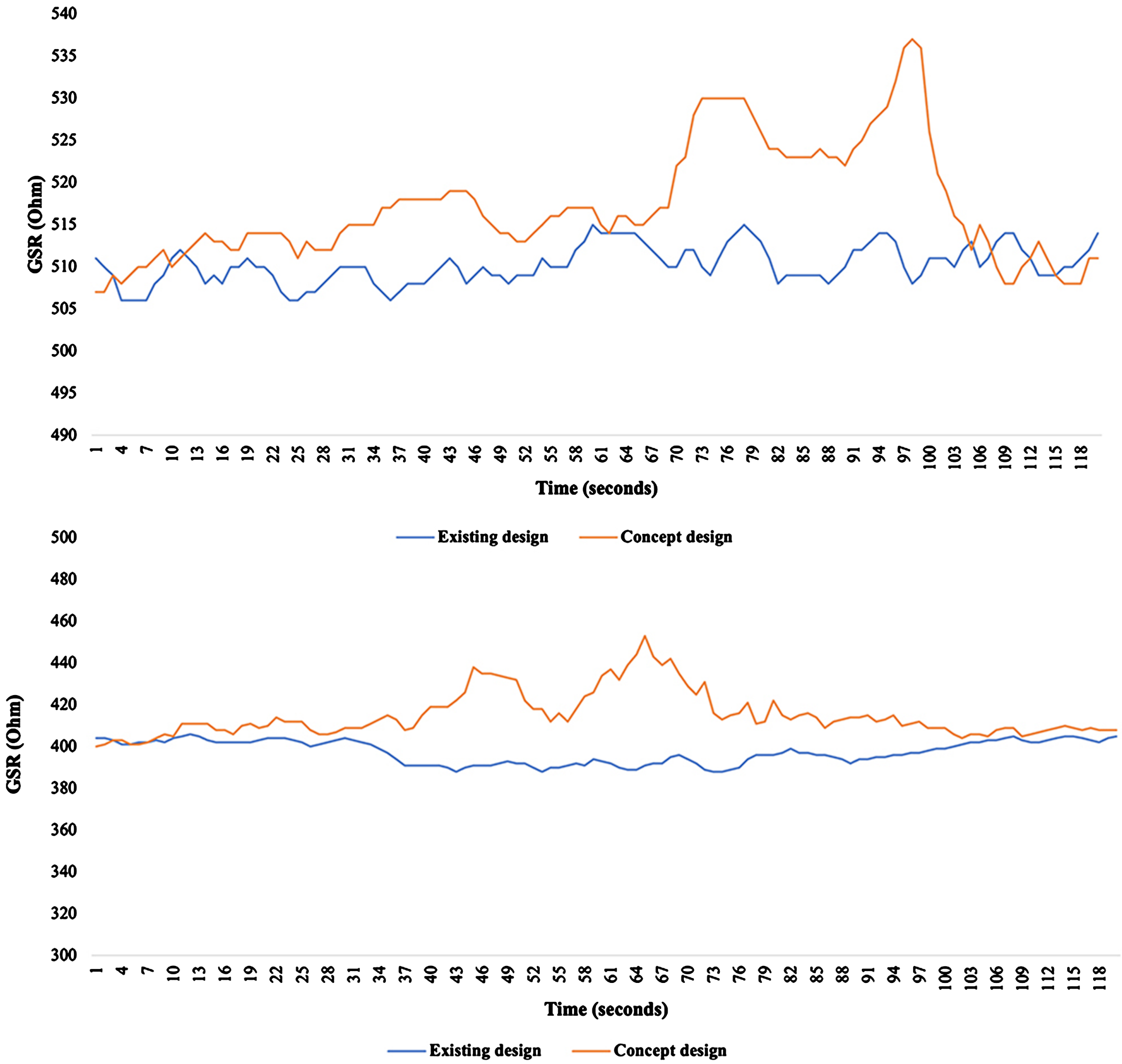

Figure 4. Sample of emotional changes in two participants.

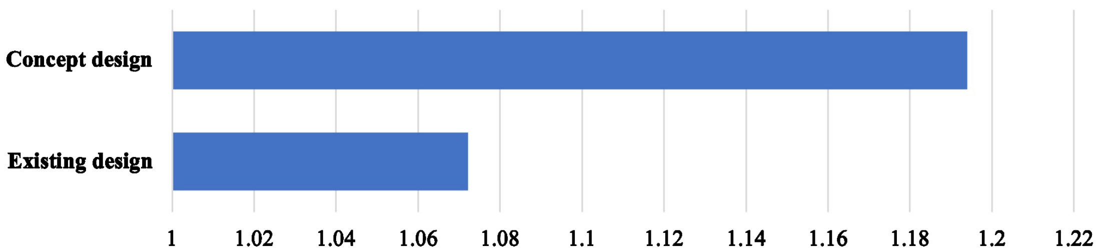

Figure 5. The intensity of participants' emotional responses to conceptual design and existing design.

design is 1.0721, whereas *EV*-value for the conceptual design is 1.1939 (Figure 5). These findings indicate that participants exhibited a much stronger emotional response towards the conceptual design.

The second part of the study involved a questionnaire survey in obtaining qualitative feedback from participants on their experience with both designs, which further validating and extending the findings of the GSR study. The results demonstrated that the majority of participants were more satisfied with the conceptual design than the existing design, with 37% and 31% of participants rating it as very satisfied and satisfied, respectively. Conversely, the existing design received mostly fair (39%) and dissatisfied (28%) ratings (**Figure 6**). The data showed that 90% of participants would recommend the concept design to others. The results indicate that the conceptual design was perceived as highly creative and provided a better experience through its theme of time travel and interactive elements, establishing a deeper connection with its context. This suggests that the conceptual design was more successful in enhancing user emotion experience. The results derived from the survey exhibited congruence with the outcomes obtained from the GSR results, thus confirming the accuracy and authenticity of the GSR data in this experiment.

4. Conclusion and Future Research

In this study, VR and GSR methodologies were employed to examine emotional responses to spatial design within regeneration projects and to establish their feasibility and efficacy. Overall, this methodology offers several advantages. Firstly, it enables researchers to create controlled and standardized environments that are less susceptible to changes in the real world. Secondly, it yields objective data on participants' emotional responses, complementing self-report measures and mitigating potential biases. Thirdly, it facilitates the visualization of design possibilities that may not yet exist or are still in development, enabling researchers to evaluate their potential impact prior to implementation. In conclusion, integrating VR and GSR methods in the investigation of emotional responses to spatial design in regeneration projects can yield invaluable insights that inform space design and planning, promoting positive emotional experiences for residents.

While the study's findings are promising, several limitations need addressing, and further refinements to the methodology are warranted. The effectiveness of experimental projects utilizing VR technology requires enhancement. The current conceptual design primarily encompasses static 3D interior visuals, thereby

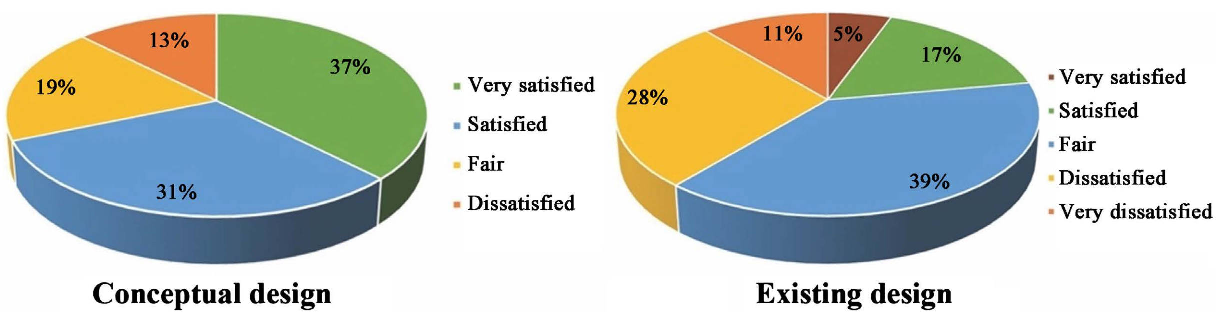

Figure 6. Participants' satisfaction with two designs.

limiting the immersive experience for participants. As these technologies advance, it is anticipated that the use of VR and GSR in research will become more sophisticated. Future studies may involve dynamic and multi-sensory VR environments that can simulate not only visual elements but also sounds, smells, and textures. GSR could also be complemented with other biometric measures to provide a comprehensive picture of emotional responses.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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