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# Designing for the mind: the impact of university environments on well-being in students by (using) neurophysiological responses

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## ABSTRACT

This study investigates the influence of different university environments on students' well-being and cognitive restoration by using neurophysiological (central – electrophysiological [EEG]) and autonomic (peripherical) responses. 31 psychology students (aged 22–28 years) were exposed to four environments in a randomized order: a traditional classroom, an atrium, a laboratory, and an immersive exhibition. EEG data frequency bands: delta, theta, alpha, beta, gamma), autonomic data (heart rate, HR; skin conductance level, SCL) and psychometric data (the Building Wellbeing Scale [BWS] and the Perceived Restorativeness Scale [PRS]) were collected. Analysis revealed significant differences in the participants' neurophysiological responses across environments. EEG results showed increased Delta and Theta activity in the temporo-parietal region during interactions with immersive environments, indicating greater cognitive engagement and relaxation. Beta activity was higher in classrooms, suggesting increased cognitive load. Autonomic measures revealed elevated skin conductance level in the atrium, indicating heightened arousal compared to other spaces. Psychometric assessments indicated that the atrium scored highest on relational well-being, while the exhibition was rated as most restorative, particularly in the coherence subscale. The atrium, with its open and naturally lit design, promoted social connection, while the exhibition fostered a restorative experience due to its engaging design. The findings suggest that environmental characteristics significantly affect both subjective and objective well-being, underscoring the importance of balancing cognitive stimulation and relaxation in academic spaces.

**Keywords:** Neuroarchitecture, EEG, Autonomic, Academic setting, Well-being, Cognitive, Emotional, Restorativeness

## INTRODUCTION

Neuroarchitecture is an interdisciplinary field that explores the interaction between human cognition, emotions, and the built environment (Karakas and Yildiz, 2020). By combining concepts from neuroscience, psychology, and architecture, it investigates how design influences mental states, emotions, and well-being (Higuera-Trujillo *et al.*, 2021). Extending the principles of environmental psychology, which historically examined the effects of physical spaces on behavior, neuroarchitecture employs neuroscientific tools like electroencephalography (EEG), autonomic measurements, and neuroimaging to deepen our understanding of these interactions (Wang *et al.*, 2022). Research underscores the role of design in shaping neural dynamics, with aesthetic appeal identified as a determinant of well-being (Higuera-Trujillo *et al.*, 2021). Furthermore, recent advancements in this field explore how architectural environments influence sensorimotor dynamics and real-world cognition. Moving beyond aesthetics, studies emphasize the necessity of designs that holistically address perception, behavior, and spatial affordances, offering innovative approaches to enhancing human experiences in built environments (Makanadar, 2024; Wang *et al.*, 2022). The understanding of the cognitive and emotional effects of architecture is particularly relevant in the context of university environments. Universities increasingly recognize the role of physical spaces in supporting student learning, mental health, and social interaction. Consequently, principles derived from architectural and environmental psychology are applied to optimize educational infrastructures, including classrooms, study areas, and communal zones, thereby fostering engagement, focus, and well-being. Theoretical frameworks, such as Attention Restoration Theory (ART; Ohly *et al.*, 2016), underscore the importance of natural elements – like green spaces – in reducing stress and enhancing attentional recovery. Furthermore, architectural features such as spatial coherence, intuitive wayfinding, and ergonomic design reduce cognitive load, facilitate navigation, and promote focus (Makanadar, 2024). Furthermore, sensory inputs, including light, sound, and color, are critical in shaping cognitive and emotional states. For instance, natural light enhances circadian rhythms, elevates mood, and boosts productivity (Blume *et al.*, 2019), while acoustically optimized spaces minimize distractions and facilitate sustained cognitive engagement (Ajiboye, 2024). However, university campuses, as multifunctional environments, consist of diverse spaces – classrooms, laboratories, libraries, and social areas – that impose distinct cognitive and emotional demands. Classrooms benefit from structured layouts that promote concentration but must also incorporate elements such as natural light and ergonomic furniture to mitigate mental fatigue (Manca *et al.*, 2020). Social areas, designed with open layouts, biophilic elements, and greenery, foster relaxation, social connectivity, and stress regulation (Zhong *et al.*, 2022). Similarly, study spaces with flexible layouts and acoustic optimization enable sustained attention and adaptability to diverse learning styles (Barrett and Zhang, 2009). Neuroarchitecture principles provide a framework for optimizing these environments to enhance both academic outcomes and mental health. Advances in neuroscientific methodologies, such as EEG and autonomic measures, have significantly transformed the study of neuroarchitecture in educational settings (Llorens-Gámez *et al.*, 2022). EEG, for example, captures brain oscillations reflecting specific cognitive and emotional states. Distinct brainwave patterns, including Delta, Theta, Alpha, Beta, and Gamma bands, are modulated by environmental factors and serve as metrics to assess the impact of design features (Cabrera *et al.*, 2021). Delta waves, linked to relaxation and emotional regulation, are often prominent in environments that encourage sensory immersion (Norwood *et al.*, 2019). Theta activity, associated with memory and creativity, is enhanced in settings that facilitate cognitive exploration (Assem *et al.*, 2023; Tawil and Kühn, 2024). Alpha waves, indicative of calm alertness, are influenced by environments that balance sensory stimulation and tranquility (Deshmukh, 2023). Beta waves, reflecting focused attention, dominate in structured settings such as classrooms (Geake, 2009). Gamma activity, associated with cognitive integration, is heightened in complex and engaging environments (Tawil and Kühn, 2024). The integration of neuroarchitecture principles into university design emphasizes creating flexible, inclusive spaces that address diverse learning needs, incorporate biophilic elements to promote well-being, and prioritize accessibility to foster inclusivity. Moreover, designs that cultivate a sense of place identity through culturally resonant architecture strengthen community ties and enhance satisfaction with the university experience. This study investigates how various architectural environments within university campuses – including classrooms, atriums, laboratories, and immersive exhibition spaces – affect students' cognitive, emotional, and physiological well-being, focusing on their influence on stress regulation, attention, and satisfaction. By examining neural and psychological responses to specific design features, the study aims to generate actionable insights for optimizing academic performance and holistic well-being. The central hypothesis posits that environments with distinct sensory and spatial characteristics elicit unique emotional and cognitive responses, thereby influencing well-being and stress regulation. Environments that promote attentional restoration and cognitive engagement are hypothesized to enhance academic performance and well-being (Higuera-Trujillo *et al.*, 2021). For example, classrooms optimized for focused work are expected to increase alpha band activity, linked to concentration, with notable activation in the left temporal-parietal region due to the cognitive demands of maintaining focus (Balconi *et al.*, 2023; Haynes, 2007). Laboratories, which require sustained cognitive effort, are hypothesized to elicit elevated beta wave activity, reflecting deep concentration (Balconi *et al.*, 2023). Immersive exhibition spaces are anticipated to enhance theta wave activity, fostering relaxation and creativity, aligning with patterns observed in engaging environments (Balconi *et al.*, 2023; Costa, 2009). Autonomic measures such as heart rate (HR), heart rate variability (HRV), skin conductance level (SCL), and skin conductance response (SCR) provide additional insights into emotional engagement and stress regulation. Restorative environments, such as exhibitions, are hypothesized to increase HRV, signifying reduced stress and enhanced recovery (Aeschbach *et al.*, 2024). These spaces are also expected to elevate SCL and SCR, reflecting heightened emotional involvement and attentional demands (Acconito *et al.*, 2023; Balconi and Fronda, 2022). To complement physiological measures, psychometric tools such as the Perceived Restorativeness Scale (PRS; Hartig *et al.*, 1997) and the Building Wellbeing Scale (BWS; Watson, 2018) will assess subjective outcomes. The PRS evaluates the restorative potential of environments in reducing stress, while the BWS assesses the impact of architectural design on well-being. By integrating neural, autonomic, and psychometric data, this study aims to provide a comprehensive perspective on designing university environments that enhance academic success and support students' cognitive, emotional, and physiological health.

## MATERIALS AND METHODS

### Sample

The sample consisted of 31 undergraduate psychology students from the Catholic University of the Sacred Heart, Milan (Mage = 23.29 years, SD = 1.32; age range = 21–28; education = 16.03 years). Inclusion criteria mandated enrollment at the Catholic University of the Sacred Heart and regular attendance, ensuring familiarity with the environment. Exclusion criteria were: (i) enrollment in another institution's master's program, (ii) cognitive, neurological, or psychiatric conditions, (iii) chronic or acute pain, and (iv) psychoactive medication use. Participation was voluntary and uncompensated. Written informed consent was obtained in accordance with the ethical guidelines of the Declaration of Helsinki (2013). The Ethics Committee of the Department of Psychology at the Catholic University of the Sacred Heart, Milan, approved the study, conducted in compliance with the General Data Protection Regulation (GDPR) - Reg. UE 2016/679 and associated ethical standards.

### Experimental Procedure

The experimental procedure consisted of four distinct step (Figure 1) that included demographic data collection, baseline recording, spatial exploration of the four university environments (a traditional classroom, an atrium, a laboratory, and an immersive exhibition), and psychometric administration.

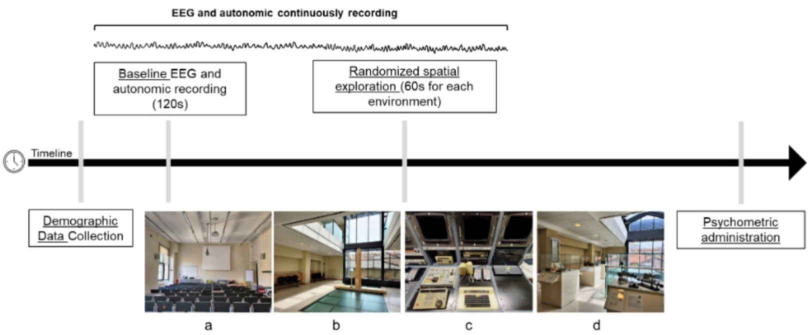


**Figure 1:** Procedure's steps and photographs of the explored spaces: (a) a traditional classroom, (b) an atrium, (c) a laboratory, and (d) an immersive exhibition.

The first step involved completing a demographic questionnaire via a Google Forms link (Google LLC, Mountain View, California, USA) before data collection began. The second step recorded baseline data under resting-state conditions using a wearable EEG (Muse Headband; InteraXon Inc., Toronto, Ontario, Canada) and a biofeedback (XPert2000; Schufried GmbH, Mödling, Austria) devices. Resting-state signals were captured over two minutes, alternating between one minute with eyes open and one minute with eyes closed. In the third step, participants proceeded to explore each environment for approximately one minute. The sequence of exploration was randomized for each participant. EEG and autonomic data were recorded during these sessions to capture physiological responses to the different settings. Finally, participants completed psychometric scales, the BWS and the PRS.

## EEG and Autonomic Data Acquisition

EEG data were recorded using the non-invasive Muse™ Headband (version 2) by InteraXon Inc. This wearable system features four bipolar dry electrodes with gold-plated conductive cups and silicon rubber. Positioned according to the 10–20 international system (Jasper, 1958), electrodes are placed at frontal (AF7, AF8) and temporo-parietal (TP9, TP10) sites on the left and right forehead and ears, respectively. Data is transmitted via Bluetooth to the Mind Monitor app, with a sampling rate of 256 Hz and a 50 Hz notch filter. The app processes raw data through Fast Fourier Transform (FFT) to extract brain wave frequencies from five bands: delta (1–4 Hz), theta (4–8 Hz), alpha (7.5–13 Hz), beta (13–30 Hz), and gamma (30–44 Hz), calculating the Power Spectral Density (PSD) for each channel. PSD values typically fall within the range of −1 to +1.

Autonomic data were collected using the X-pert2000 portable Biofeedback system with a MULTI radio module (Schuhfried GmbH, Modling, Austria). A peripheral sensor was placed on the distal phalanx of the non-dominant hand's second finger to measure electrodermal activity, including SCL and SCR, as well as cardiovascular indices such as HR and HRV. SCL and SCR were recorded in $\mu$S using a gold EDA electrode with current-current measurement at a 2 kHz sampling frequency, and alternating voltage was applied to prevent polarization. SCL resolution was 12 nanoseconds (ns) with a 20 Hz sampling rate. HR, measured in beats per minute (bpm), was captured via photoplethysmography at a 500 Hz sampling frequency. Hand movements were monitored with an accelerometer (calibrated in $m/s^2$) on the sending unit to mitigate movement interference during recordings.

## Data Analysis

The EEG data were analyzed using repeated measures ANOVA with SPSS (version 27; IBM Corp., Armonk, NY, USA) to assess the effects of frequency bands, regions of interest (ROI), and hemispheric lateralization on brain activity. Five separate repeated measures ANOVAs were conducted for each frequency band (Delta, Theta, Alpha, Beta, Gamma). The independent variables included the following factors: ROI (frontal, temporo-parietal), hemispheric lateralization (right, left), and environments (four). Furthermore, four repeated measures ANOVAs were performed for each autonomic index

(HR, HRV, SCL and SCR) with environments (four) as the within-subject factor. Finally, univariate ANOVAs were performed for each subscale of the BWS and PRS with environments (four) as the between-subjects factor. Pairwise comparisons were applied to the data in case of significant effects. Polynomial contrasts were computed to evaluate potential linear or higher-order trends across locations. Post-hoc pairwise comparisons were performed with Bonferroni adjustment to control for Type I error. Effect sizes ($\eta^2$) were calculated to assess the magnitude of the observed effects, and observed power was reported to evaluate the likelihood of detecting significant results given the sample size. Statistical significance was set at $\alpha = 0.05$. All data were inspected for violations of sphericity using Mauchly's test, and Greenhouse-Geisser corrections were applied when necessary.

## RESULTS

### EEG and Autonomic Results

*Delta*. The analysis of variance revealed a statistically significant effect for ROI ($F_{[1,24]} = 19.944$, $p = .000$, $\eta^2 = .453$), with an increase in Delta activity in the temporo-parietal area compared to the frontal area. A statistically significant interaction effect was found for ROI × environment ($F_{[2,72]} = 3.681, p = .031; \eta^2 = .132$), indicating an increase in Delta activity in the temporo-parietal area across each of the four environments considered compared to the frontal area. Finally, a significant interaction effect was recorded for Lateralization × environment ($F_{[3,72]} = 3.784$, $p = .014$, $\eta^2 = .136$). Pairwise comparisons revealed a statistically significant difference in Delta activity between the laboratory and the immersive exhibition in the left hemisphere, highlighting higher activation in the laboratory environment ($\mu = 1.628$) compared to the immersive exhibition.

*Theta*. A significant main effect was found for Localization ($F_{[1,24]} = 17.860$, $p = .000$, $\eta^2 = .426$), with higher activation of the Theta band in the temporo-parietal area compared to the frontal area.

*Beta*. A statistically significant effect was found concerning the Lateralization variable ($F_{[1,24]} = 4.338$, $p = .048$, $\eta^2 = .153$), with an increase in Beta band activation in the left hemisphere compared to the right hemisphere.

*Gamma*. A statistically significant main effect was found for Localization ($F_{[1,24]} = 4.492$, $p = .445$, $\eta^2 = .157$), with an increase in Gamma band activation in the temporo-parietal area compared to the frontal area.

*SCL*. A significant main effect was found for the Environment variable ($F_{[3,45]} = 4.305$, $p = .009$, $\eta^2 = .223$), with higher skin conductance levels in the atrium environment compared to the classroom environment. No significant differences were found for HR, HRV, and SCR.

### Psychometric Results

*BWS*. For the Rationality subscale, a statistically significant effect was found for environment ($F_{[3,27]} = 3.322$, $p = .034$, $\eta^2 = .270$), with higher levels of relationality observed in the atrium compared to the classroom (Figure 1a). No other significant effects were found.

*PRS*. For the Coherence subscale, a statistically significant effect was found for environment ($F_{[3, 27]} = 6.823$, $p = .001$, $\eta^2 = .431$). Specifically, higher levels of coherence were observed in the exhibition environment compared to the laboratory environment ($p = .003$). Additionally, coherence was higher in the classroom environment compared to the laboratory environment ($p = .007$).

## DISCUSSION

The present study aimed to investigate the complex interplay between university environments and students' neurophysiological, emotional, and cognitive well-being, contributing to the broader field of neuroarchitecture. The findings revealed significant variations across these environments. Delta and Theta demonstrated a marked increase in the temporo-parietal region during the exploration of immersive and socially engaging spaces. In contrast, Beta activity was predominantly observed in the classroom environment, reflecting the structured and cognitively intensive nature of this setting. Among the examined environments, the atrium was associated with the highest scores for relational well-being, whereas the exhibition space was identified as the most restorative, underscoring the critical role of spatial coherence and sensory engagement in fostering cognitive and emotional benefits. These findings highlight the relationship between environmental features and cognitive restoration. Environments characterized by coherence and sensory engagement appear to facilitate the replenishment of attentional resources, as evidenced by the increased Theta activity and the restorative ratings of the exhibition space. The immersive qualities of this environment appear to have significantly contributed to facilitating cognitive recovery and enhancing emotional regulation, underscoring the intricate interdependence between spatial design elements and neural processes. The theoretical framework of ART posits that exposure to environments with coherence and engagement significantly facilitates the replenishment of attentional resources, thereby enhancing both cognitive performance and emotional stability (Ohly *et al.*, 2016). This is evident in the exhibition space, where the coherence subscale of the PRS and increased Theta activity reflected the environment's potential to foster cognitive restoration. Furthermore, the immersive design elements likely enhanced participants' engagement, corroborating ART's emphasis on the role of sensory immersion in cognitive recovery. Delta oscillations, traditionally linked to states of rest and subconscious cognitive processing, showed significant activation in the temporo-parietal region, aligning with theories of episodic memory and social cognition. Delta waves are fundamental to processes governing emotional memory and feedback, particularly in contexts that elicit familiarity and facilitate episodic recollection (Balconi *et al.*, 2018, 2024). This neural response was especially pronounced in the laboratory and exhibition settings, where novelty and coherence likely triggered episodic memory retrieval and attentional processes. The significant Theta activity observed in the temporo-parietal region aligns with its role in memory encoding, emotional regulation, and stress relief. This finding underscores the restorative value of environments like the exhibition, which combines novelty and coherence to promote cognitive and emotional balance. The role of the temporo-parietal region in these processes is further supported by recent research that highlighted its involvement in theory of mind, empathy, and episodic memory (Allegretta *et al.*, 2024; Balconi and Vanutelli, 2017) – processes that are particularly relevant in socially and emotionally engaging settings like the atrium and exhibition. Beta activity, predominantly observed in the classroom environment, reflects the structured and cognitively demanding characteristics of this setting. Beta oscillations, linked to sustained attention and problem-solving (Geake, 2009), indicate the classroom's role in supporting focused cognitive tasks.

The autonomic findings, particularly the elevated SCL in the atrium, highlight the physiological arousal associated with open, well-lit environments. This observation aligns with existing research on the role of spatial openness and natural lighting in enhancing emotional engagement and facilitating social interaction. The significance of spatial symmetry and illumination in promoting positive emotional states has been emphasized (Shemesh *et al.*, 2022), which is consistent with the atrium's high relational well-being scores.

The psychometric results provide further insight into the interplay between relational and restorative qualities of academic spaces. The atrium's high relational scores align with models of place attachment, which identify socio-emotional and functional values as key determinants of environmental satisfaction. Similarly, the coherence observed in the exhibition and classroom settings reflects the concept of coherence as a defining feature of restorative environments (Hauru *et al.*, 2012). These findings validate the emphasis on the importance of spatial design in promoting both individual and collective well-being.

In conclusion, this study underscores the critical role of neuroarchitecture in designing academic spaces that cater to diverse cognitive and emotional needs. By leveraging theoretical frameworks like ART and integrating neuroscientific insights, the findings emphasize the importance of coherence, sensory engagement, and biophilic elements in fostering holistic well-being. Future research should explore the longitudinal impact of such designs on academic performance and extend investigations to diverse cultural and architectural contexts. Ultimately, this study highlights the transformative potential of evidence-based design principles in shaping educational environments that not only support learning but also nurture cognitive and emotional health.

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**Ethics Statement:** The study involving human participants was conducted in accordance with the Declaration of Helsinki (2013), reviewed and approved by the Ethics Committee of the Catholic University of the Sacred Heart, Milan, Italy (approval code: 2021 PhDTD; approval date: 1 December 2021).

**CRediT**: MB: Conceptualization, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. KR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft.

**Consent to Participate:** The participants provided their written informed consent to participate in this study.

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**Data Availability Statement:** The data presented in this study are available on request from the corresponding author due to ethical reasons for sensitive personal data protection (requests will be evaluated according to the GDPR - Reg. UE 2016/679 and its ethical guidelines).

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