



同濟大學
TONGJI UNIVERSITY

硕士学位论文

(专业学位)

面向工作空间设计的神经建筑学框架 — 从神经科学证据到建筑设计

姓 名:

学 号:

学 院:

学科门类: 工学

专业学位类别: 建筑学

专业领域: 建筑学

研究方向:

指导教师:

行业导师:

联合培养单位:

二〇二三年六月



同濟大學
TONGJI UNIVERSITY

A thesis submitted to

Tongji University in partial fulfillment of the requirements for
the degree of Master of Architecture

**A NEUROARCHITECTURAL FRAMEWORK FOR
WORKSPACE DESIGN**

from neuroscientific evidence to architectural design

Candidate: Passport Name

Student Number:

School/Department: College of architecture and urban
planning

Categories: Engineering

First-level Discipline/Degree: Architecture

Second-level Discipline/Degree's Field: Architecture

Research Fields:

Supervisor:

Associate Supervisor:

Joint Training Institution:

April, 2026

面向工作空间设计的神经建筑学框架

姓名

同济大学

ABSTRACT

The architecture of contemporary workspaces faces a profound neuroergonomic crisis. Dominant models, namely the Taylorist cellular office and the conventional open plan, often fail to support cognitive and perceptual well-being, generating either sensory deprivation or chronic hypervigilance. This thesis investigates the impact of spatial configuration on neurobiological wellbeing, replacing formal arbitrariness with an Evidence-Based Design approach.

The research examines how the calibration of Visual Openness and Perceived Complexity can modulate attention and allostatic load. A hybrid methodology was adopted. Four virtual scenarios were experienced in Mixed Reality while participants walked through corridor-based spatial sequences, and electroencephalography was used to observe neurophysiological activation patterns. These configurations were subsequently analysed computationally through Isovist extraction and Edge Density calculation.

The findings challenge the assumptions of traditional workplace layouts, suggesting that neuroergonomic optimisation depends on a calibrated balance between visual depth, proxemic protection, and controlled morphological complexity, rather than on the mere reduction of stimuli. Rather than privileging either enclosure or total openness, the most effective spatial condition combined visual continuity with protective thresholds, supporting orientation, reducing spatial anxiety, and sustaining attentional regulation.

These bio spatial parameters informed the architectural retrofit of Floor G within the historic “La Nave” building in Pavia, where the rigid orthogonal grid was reinterpreted through transparent partitions, opaque lower elements, and curvilinear geometries. In this way, the project translates neuroarchitectural evidence into spatial form, framing architecture not as a passive container but as an active cognitive infrastructure. This integration opens new perspectives for neuroarchitecture and inclusive design, establishing a basis for workspaces that respond more effectively to human cognitive and perceptual needs.

Key Words: Neuroarchitecture, Evidence-Based Design, Electroencephalography, Mixed Reality, Cognitive load.

CONTENTS

1. INTRODUCTION	9
1.1 Background	9
1.2 Research problems	10
1.2.1 <i>The cognitive role of public areas in the workspace</i>	13
1.3 Research significance and current constraints	14
1.4 Research question	16
1.5 Research content	19
2. THEORETICAL FOUNDATION AND STATE OF THE ART	22
2.1 The evolution of workspace: from Taylorism to neuroarchitecture	22
2.2 Psychological frameworks for spatial design	26
2.2.1 <i>Attention Restoration Theory (ART)</i>	27
2.2.2 <i>Prospect-Refuge Theory</i>	28
2.2.3 <i>Arousal Theory</i>	30
2.3 Evidence-Based Design (EBD)	31
2.3.1 <i>Medical genesis: the clinical impact of space</i>	31
2.3.2 <i>Definition and methodological rigour</i>	32
3. METHODOLOGY	33
3.1 Introduction	33
3.2 Research design	35
3.3 Operational definition of the architectural variables	36
3.3.1 <i>The morphological matrix: “La Nave” (floor G)</i>	36
3.3.2 <i>Parametric computation of Visual Openness (VO)</i>	37
3.3.3 <i>Algorithmic extraction of Perceived Complexity (PC)</i>	39
3.4 Participants	41
3.5 Experimental methodology (MR-EEG protocol)	42
3.5.1 <i>Equipment</i>	42
3.5.2 <i>The space exploration task</i>	44
3.6 Psychometric assessment	45
3.7 Experimental procedure	46

3.8 Data observation and qualitative analysis	47
4. CASE STUDY: NEUROARCHITECTURAL ANALYSIS OF FLOOR G (LA NAVE AT CRAVINO CAMPUS IN PAVIA)	48
4.1 Site analysis: Giancarlo De Carlo's "La Nave" at Cravino Pole (Pavia, Italy)	48
4.1.1 <i>The local context</i>	48
4.1.2 <i>Giancarlo De Carlo's concept</i>	49
4.1.3 <i>The current spatial configuration and floor G</i>	52
4.1.4 <i>Quantitative spatial analysis of the existing configuration</i> ...	54
4.2 Functional assessment of floor G	56
4.2.1 <i>Existing layout and workspace organization</i>	56
4.2.2 <i>Spatial criticalities for cognitive work</i>	57
4.2.3 <i>User flow analysis and movement patterns</i>	58
4.3 From real space to experimental model	59
4.3.1 <i>Structural invariants and geometric constraints</i>	59
4.3.2 <i>Definition of the morphological bounding box for MR simulation</i>	60
5. GENERATION OF SCENARIOS AND PARAMETRIC VALIDATION	61
5.1 Generation of the virtual scenarios	61
5.1.1 <i>Abstract typological exploration and scenario selection</i>	62
5.1.2 <i>Scenario 1 (Baseline): Low VO/Low PC</i>	64
5.1.3 <i>Scenario 2: High VO/Low PC</i>	65
5.1.4 <i>Scenario 3: Low VO/High PC</i>	67
5.1.5 <i>Scenario 4: High VO/High PC</i>	68
5.2 Parametric validation of the spatial variables	70
5.2.1 <i>Validating VO using Isovist analysis</i>	70
5.2.2 <i>Validation of PC using Edge Density</i>	73
5.3 Experimental execution and methodological limitations	75
5.3.1 <i>Laboratory setup and hardware coexistence</i>	75
5.3.2 <i>Execution of motor sessions and EEG artefact management</i>	76
5.3.3 <i>Spatial safety and ecological validity</i>	76
5.4 Synthesis of experimental setup	77
6. DATA ANALYSIS AND NEUROERGONOMIC RESULTS	79

6.1	Demographics and data treatment.....	79
6.2	Psychometric assessment	80
6.2.1	<i>Spatial presence and ecological validity</i>	82
6.2.2	<i>Environmental assessment</i>	83
6.2.3	<i>Cognitive load and stress</i>	85
6.2.4	<i>Behavioural intent and workplace feasibility</i>	86
6.3	Objective EEG data.....	87
6.3.1	<i>Cognitive load and concentration (Frontal Theta)</i>	88
6.3.2	<i>Visuospatial stress (Parieto-Occipital Alpha)</i>	90
6.4	Discussion and neuroergonomic triangulation.....	91
7.	EVIDENCE-BASED DESIGN APPLICATION.....	93
7.1	From experimental data to architectural concept.....	93
7.2	Cognitive-Based Zoning	94
7.2.1	<i>Transparent cellularity for focal work</i>	95
7.2.2	<i>Decompression zone and attentional restoration</i>	96
7.3	Neuro-sensory materiality and environmental control	96
7.3.1	<i>Chromatic orientation and neuro-illuminotechnical control</i> ...	97
7.3.2	<i>Integrated acoustic and material biomimicry</i>	97
7.4	Parametric validation of the proposed layout	98
7.4.1	<i>Recalculating Visual Openness (VO)</i>	98
7.4.2	<i>Recalculating Perceived Complexity (PC)</i>	99
7.4.3	<i>Comparative analysis of surfaces (real estate trade-off)</i>	100
7.4.4	<i>Conclusion of the design phase</i>	102
8.	CONCLUSIONS AND FUTURE DEVELOPMENTS	103
8.1	Response to research questions and summary of results	103
8.2	Study limitations and uninvestigated variables.....	103
8.3	Future developments and disciplinary perspectives	105
	Reference list	107
	List of figures.....	117
	List of tables	122
	List of acronyms	123
	Glossary of Key Terms	126

Appendix A - PARTICIPANT INFORMATION SHEET	131
Appendix B - PYTHON SCRIPT FOR EDGE DENSITY CALCULATION	134

1. INTRODUCTION

1.1 Background

The built environment is not only a physical envelope but a continuous modulator of human cognition and behaviour (Eberhard, 2008). Architectural practice has traditionally relied on design intuition, as well as spatial efficiency and economic considerations. However, in today's knowledge economy, this approach is no longer sufficient, especially in the context of workspaces. Many knowledge-work tasks require sustained concentration and executive attention, but there is a significant mismatch between neurobiological constraints and workspace morphology, leading to a depletion of cognitive resources (Saval, 2014). This mismatch can turn the environment from a beneficial tool to a potential source of stress, highlighting a crisis of effectiveness for architectural design.

The need to bridge this gap has led to the emergence of a new research paradigm: the neuroarchitecture. This discipline emerged at the beginning of the 21st century with the establishment of the Academy of Neuroscience for Architecture (ANFA), combining the science of architectural design with the quantitative methods and research tools of cognitive neuroscience (Eberhard, 2008). Neuroarchitecture rests on the assumption that certain environmental factors, such as spatial geometry and visual complexity, can modulate the activity of neural networks and influence attentional performance and emotional homeostasis (Banaei, Hatami, Yazdanfar, & Gramann, 2017). This allows the discipline to move beyond purely aesthetic speculation and rely on *Evidence-Based Design* (EBD), where design decisions are validated through rigorous testing of objective physiological parameters (Ulrich, 1984).

In this context, the present study aims to apply a neuroarchitectural protocol for the optimisation of workspaces, rather than relying solely on Post-Occupancy Evaluation (POE) tools, which are potentially affected by self-assessment bias (Zimring, Joseph, Nicoll, & Tsepas, 2005). The study seeks to develop a methodology based on objective parameters. The approach aims to measure users' involuntary neurophysiological reactions to specific environmental changes, identifying factors that may contribute to cognitive overload through controlled simulation. The study aims to translate neuroscientific evidence into measurable architectural parameters,

formulating concise and quantifiable guidelines to inform workspace design that supports individual well-being and performance.

1.2 Research problems

The built environment of contemporary workspaces imposes a high and largely invisible cost on the cognitive performance of its occupants (Saval, 2014). Workplace design is not merely an aesthetic and utilitarian construct but is also a strong neurophysiological regulator that can exert a profound influence on users' cognitive performance and metabolic well-being. When this discrepancy is sustained over time, it generates a measurable physiological burden that extends beyond individual discomfort to encompass significant clinical and economic consequences (Evans & Johnson, 2000; Hemp, 2004).

The primary method through which the built environment influences cognitive abilities can be conceptualized using the construct of Allostatic Load, defined by the medical community as the biological wear and tear caused by prolonged exposure to stressors. The human brain requires significant cognitive resources to constantly filter out unpredictable sensory stimuli (Evans & Johnson, 2000). Therefore, in an open-plan or Activity-Based office, incessant peripheral auditory and visual stimuli require the prefrontal cortex to work continuously and energetically to inhibit distraction. This prolonged demand can chronically activate the hypothalamic-pituitary-adrenal (HPA) axis, leading to the overproduction of stress hormones, particularly epinephrine and cortisol (Evans & Johnson, 2000). Recent studies have demonstrated a significant association between poor indoor environmental quality and clinically significant increases in allostatic load scores among knowledge workers (Jung, Liang, Lee, Hsu, & Su, 2014).

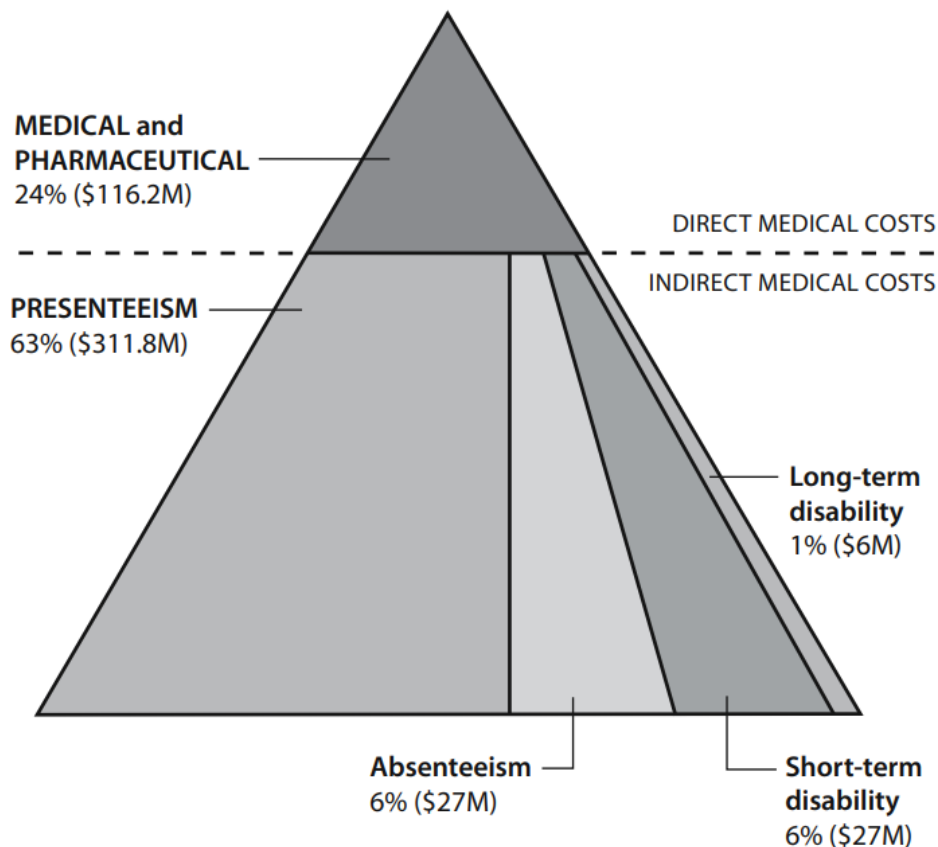
When physiological wear exceeds the capacity of the nervous system to respond with resiliency, discomfort becomes chronic, and measurable environmental disturbances are manifest, primarily Sick Building Syndrome (SBS) (Seppänen & Fisk, 2001). Current theories of the aetiology of SBS, which have traditionally been associated with infrastructural and environmental issues such as poor ventilation or indoor pollution, also consider the role of psychosocial and spatial factors as highly aetiologically significant factors (Oktavia, Setiani, & Joko, 2026). The allostatic load model offers a bridge between the biological and the environmental factors as the

1.INTRODUCTION

brain processes the chronic stress of inadequate spatial privacy, high density of occupants, and lack of control over one's microclimate as a means of constant sensory filtering. This cognitive depletion is considered a significant contributing factor to the symptoms associated with SBS: severe headaches, high mental fatigue, and irritability (Oktavia et al., 2026; Seppänen & Fisk, 2002; Jung et al., 2014; Surawattanasakul et al., 2022).

According to the International Ergonomics Association, ergonomics can be defined as the scientific discipline that seeks to understand the relationship between humans and other elements of a system, to optimise human well-being and the overall performance of the system ('What Is Ergonomics (HFE)? | International Ergonomics Association', n.d.). In the past, ergonomics was applied primarily to the workplace, in relation to physical health, particularly body posture and the prevention of musculoskeletal disorders. However, for knowledge workers, the most critical interface is the cognitive one, and this has led to the need to turn to neuroergonomics, which has been described as the application of neuroscience to human factors, to understand the brain's limited capacity to process environmental stimuli and maintain attention (Diarra, Theurel, & Paty, 2025). Indeed, serious neuroergonomic problems arise when workspaces are designed without taking these neurological limitations into account, which can result in chronic sensory overload and distraction.

Neuroergonomic failure has significant economic implications, particularly regarding the Return on Investment (ROI) of cost-saving strategies in the property sector, which have been implemented over the last few decades by corporate management. Epidemiological and economic studies using World Health Organization-Health and Productivity Questionnaire (WHO-HPQ) metrics have shown that the cost of productivity loss due to presenteeism far exceeds the cost of absenteeism. Baseline studies show around 57.5 days of lost productivity per year due to presenteeism, compared to 4 days due to absenteeism (Enhessa, 2024; Hemp, 2004). More recently, the Workplace Wellbeing 360 Report 2025 has supported the continued rise in presenteeism, estimating the cost of presenteeism to be at least three to ten times higher than that of physical absence, depending on the industry ('Workplace Wellbeing 360 Report 2025 - Intellect | Modern-Day Mental Healthcare For Asia', n.d.). The huge cost implications clearly highlight that ignoring the neuroergonomic constraints of employees is no cost-effective measure but a huge liability for organizations (European House Ambrosetti & Angelini Pharma, 2023; Hemp, 2004).



Source: Bank One

Figures are based on annual data for 2000. Workers' compensation accounted for less than 1% of indirect medical costs.

Copyright © 2004 Harvard Business School Publishing Corporation. All rights reserved.

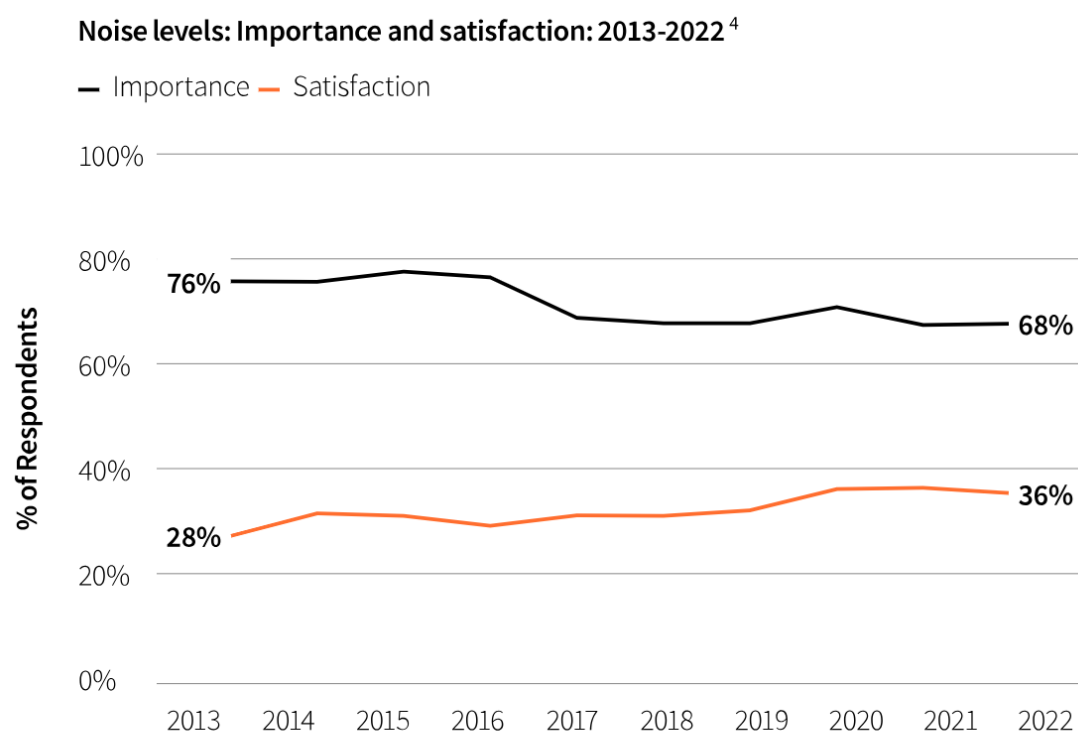
Figure 1.1: The financial impact of presenteeism on employers' health-related costs. Productivity lost to presenteeism accounts for the vast majority (**63%**) of total costs, significantly overshadowing direct medical costs and traditional absenteeism. Source: [Reprinted from Hemp (2004, p. 54)]

This scenario is confirmed by data from the Center for the Built Environment (CBE) at the University of California, Berkeley, which maintains one of the world's largest databases based on post-occupancy evaluations (POE). A retrospective analysis of over 90,000 questionnaires collected over two decades showed that acoustic privacy and noise levels consistently rank lowest, with dissatisfaction rates of 54% and 34%, respectively, and are the two main indicators of overall workplace dissatisfaction (Graham, Parkinson, & Schiavon, 2021). Previous studies based on the same database have also highlighted that the lack of visual and acoustic privacy in open-plan offices has the most significant negative impact on worker productivity (Frontczak et al., 2012).

These findings are further corroborated by contemporary POE databases. Data

1.INTRODUCTION

from the Leesman Index 2023, currently one of the leading independent repositories on workplace experience, indicate that around 30% of employees report being satisfied with acoustic conditions in open-plan offices, confirming that noise and a lack of privacy constitute a barrier to deep, focused work (Figure 1.2) (Ltd, 2024; ‘The Inevitability of Change - Leesman’, 2023). However, whilst such POE databases are essential for identifying patterns of widespread discomfort, they are based solely on subjective questionnaires and are therefore subject to self-reporting bias. This limitation makes it necessary to look beyond mere perceived dissatisfaction and introduce objective neuroergonomic measures capable of quantifying the actual cognitive cost imposed by such working environments.



⁴ Leesman Office respondents, N=1,062,449 (2013 - 2022)

Figure 1.2: Noise levels – importance and satisfaction. Leesman Index 2023. Source: [Leesmanindex].

1.2.1 The cognitive role of public areas in the workspace

Neuroergonomic analysis of the contemporary office environment is typically limited to the efficiency of individual management positions. A systems approach would require going beyond this paradigm. Academic literature in environmental psychology and organizational architecture demonstrates how the work environment

operates as a complex ecosystem, in which public and shared spaces play a crucial role (Allen & Henn, 2007; Sailer & Penn, 2009). Such shared spaces, which include circulation paths and informal zones, provide an essential infrastructure to mitigate the allostatic load generated by prolonged work (S. Kaplan, 1995; Ulrich et al., 1991).

This dynamic has considerable significance in modern Activity-Based Working models. In these dynamic configurations, workers are constantly pushed to navigate the space, moving away from their fixed station to attend meetings, reach colleagues, or relax in common areas. Therefore, movement through open spaces becomes one of the most important physical interactions with the architectural environment. During these shifts, the nervous system continuously processes information about spatial depth, edge density, and peripheral visual inputs. The latest findings indicate that a high level of visual input in open spatial configurations increases cognitive inhibitions in the prefrontal cortex (Eaton, 2026; Libby Sander, 2026). Excessive complexity and excessive visual input in public circulation areas can cause spatial disorientation and sensory overload. Such an approach nullifies the regenerative potential of shared space and induces even greater neurological exhaustion.

Given these neurobiological limitations, this study defines the workspace comprehensively, placing the primary focus of investigation specifically on public areas. Within the broader ecosystem of shared spaces, the present research isolates and analyses exclusively the dynamic component. The experiment specifically evaluates the experience of spatial navigation and wayfinding, focusing on the circulation flows that connect different office zones. This methodological choice enables the quantification of the cognitive load and proxemic stress generated by the architectural environment during the user's active movement through the shared space, establishing a foundation for evidence-based design optimization.

1.3 Research significance and current constraints

Although support for the application of EBD in workplace planning continues to grow, its methodological limitations remain significant. Traditionally, the assessment of environmental well-being has been possible only through post-occupancy evaluation (POE). While such sociological tools are useful for determining macroscopic trends in user satisfaction, the reliability of results obtained through this method is inherently limited, as self-report bias cannot be avoided (Zimring et al.,

2005). Human cognition has limited accuracy in self-assessment: a human subject might experience cognitive fatigue, which they might attribute to noise, while the actual neurobiological trigger could result from excessive visual exposure or a lack of proxemic refuge.

Another limitation identified by the current state of the literature on neuroarchitecture concerns the scope of investigation. In recent years, academic literature has focused on the aesthetic evaluation of the spatial environment and the integration of passive elements, such as indoor vegetation and natural lighting (Higuera-Trujillo, Llinares, & Macagno, 2021). Systematic and in-depth research on the cognitive impact of morphological and geometric variables, such as visual openness and perceived complexity, remains fragmented. These spatial configurations define the unchanging framework of architecture, and their ability to modulate the user's attentional load cannot be circumvented or mitigated by simple interior design interventions.

Conceptual gaps in the literature are compounded by the inherent limitations of traditional diagnostic tools. For a long time, neural research on spatial perception has been constrained by the predominant reliance on functional Magnetic Resonance Imaging (fMRI), a technique that limits the ecological validity of the assessment experiment by forcing the subject to evaluate simulations while lying supine and in a decontextualized setting (Banaei et al., 2017). More recently, although the introduction of Virtual Reality (VR) marks a significant step forward, it often requires a high degree of perceptual isolation from the physical environment, which can influence psychophysiological responses, especially in the workplace (Shemesh, Leisman, & Grobman, 2026). In this sense, the implementation of Mixed Reality (MR) protocols associated with Mobile Brain/Body Imaging (MoBI) systems, a methodology that allows for the recording of electroencephalographic activity in subjects who are moving or actively interacting with the environment, represents a methodological breakthrough of great interest. High-fidelity MR allows virtual spatiality to be superimposed onto real haptic objects, such as the physical boundaries and pathways, ensuring authentic motor and perceptual interaction while preserving rigorous experimental control over architectural alterations (Lee & Kim, 2024).

The scientific significance of this study lies precisely in overcoming these procedural limitations. The study goes beyond recommendations based on design intuition; rather, it establishes a measurable link between the perception of spatial

geometry and quantitative neuroergonomics. The research aims to identify, through the combined use of electroencephalography (EEG) and Mixed Reality (MR), the impact of different public area configurations on neurophysiological measures of arousal and proxemic stress in the process of active exploration. This process of modulation can be investigated by combining psychometric evaluation with the qualitative observation of EEG patterns, bypassing the biases of standard post-occupancy surveys. The outcome of this investigation aims to support the transition of architectural practice from a discipline based on descriptive observation to a predictive modelling approach.

In the context of this investigation, it is necessary to accurately determine its epistemological boundaries. This study should be considered as methodological research of a new design approach, neuroarchitecture, emphasizing the application of these tools on a specific case study. The primary objective is to demonstrate the validity of the design process. The use of neurophysiological data allows us to decipher space, identify hidden neuroergonomic issues, and develop strategies based on objective parameters. Consequently, the study does not seek to formulate universal scientific rules on maximum work efficiency but rather serves as a tool to support architectural practice.

In parallel, it is essential to justify an important methodological choice regarding the nature of the experimental process. As explained above, spatial experience is inevitably conditioned by multiple simultaneous sensory aspects, including lighting, colours, material surfaces, and furnishings. Geometry represents the primary architectural component, specifying the primary structure of the space, proportions and navigation paths. Therefore, the research selects two geometric variables (Visual Openness and Perceived Complexity) that are used as the exclusive entry point for the neuroarchitectural approach. These two variables are intentionally separated within the simulation models, excluding textures and colours, so as not to induce any changes in the electroencephalographic signal. The material dimensions find their correct and complete application exclusively in the subsequent design phase.

1.4 Research question

In response to the research gap identified in the previous section, relating to the absence of objective neurophysiological metrics capable of overcoming the biases

introduced by Post-Occupancy Evaluation questionnaires (Zimring et al., 2005), the present empirical investigation adopts a selective analytical approach. Although the aetiology of workplace discomfort is intrinsically multisensory, with a primary role historically assigned to acoustic privacy deficiency (Graham et al., 2021), this study isolates the cognitive impact of spatial morphology.

To this end, the investigation examines the impact of two specific visual-geometric variables: Visual Openness (VO) and Perceived Complexity (PC). The assessment will be conducted through an advanced neuroarchitectural protocol that combines high-fidelity Mixed Reality (MR) technology with a mobile electroencephalography (EEG) device.

This methodological framework ultimately leads to the formulation of the following research question:

How do variations in workspace public areas, specifically Visual Openness and Perceived Complexity, affect users' cognitive load and stress responses during active spatial exploration, and how can these quantified effects inform evidence-based design optimization?

To make this research question verifiable from a scientific point of view, the theoretical frameworks discussed above have been adapted for an active, standing exploration paradigm and operationalized into the following directional hypotheses:

1. **H1 (The threshold effect of VO):** It is hypothesized that the transition from a closed space (Low VO) to an open space (High VO, characterized by partitions as low as 1.2 m) is expected to result in an immediate increase in cognitive load and spatial stress, indexed by qualitative changes in Frontal Alpha Asymmetry. This effect is induced by peripheral spatial stimuli and by the exposure of the body in an upright posture, regardless of the geometric articulation of the walls.
2. **H2 (Morphological sensitivity in confined spaces):** It is hypothesized that, in a closed space (Low VO), the introduction of a non-orthogonal space (High PC) may dominate the user's central field of vision, imposing a significant increase in perceived complexity. This is expected to manifest through observable patterns of increased frontal Theta activity and reduced parietal Alpha power with respect to the orthogonal variant, which are commonly interpreted as reflecting a greater executive and visuo-spatial processing effort.

3. **H3 (The Interaction Effect and the Paradox of the Labyrinth):** A nonlinear interaction between VO and PC is assumed. In an open space (High VO), the irregular geometry (High PC) should induce marginal variations in the visual density (Edge Density) already saturated by the depth of field. It is hypothesized that any stress peaks encountered in this context do not derive from excessive visual complexity, but from topological disorientation and the wayfinding effort required to decode a fragmented and labyrinthine spatial grid.

To verify the formulated hypotheses and answer the formulated Research Question, the study has been designed to pursue three sequential objectives:

1. **O1:** To assess the impact of spatial morphology within public areas on neurophysiological and psychometric measures of arousal and spatial stress during active exploration, using an experimental protocol that incorporates mobile EEG recording and Mixed Reality simulations in a controlled laboratory setting.
2. **O2:** To synthesize the empirical results into a set of EBD parameters, identifying the spatial thresholds of VO and PC that minimise cognitive load within the tested virtual environments.
3. **O3:** To apply these parameters to the office space of the selected case study "La Nave", Cravino Pole (Pavia), proposing a data-driven spatial retrofit tailored to its structural constraints.

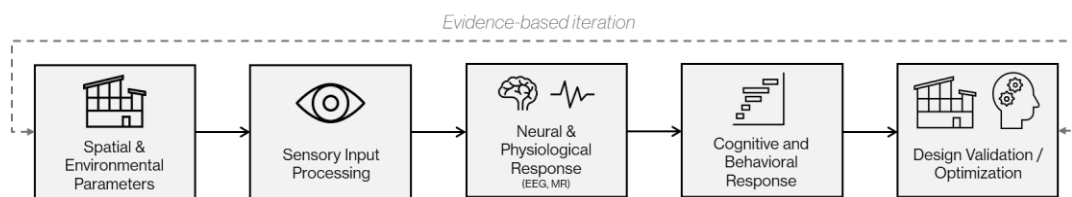


Figure 1.3: Systematic workflow linking architectural variables with quantifiable neural and behavioural outcomes.
Source: [Author].

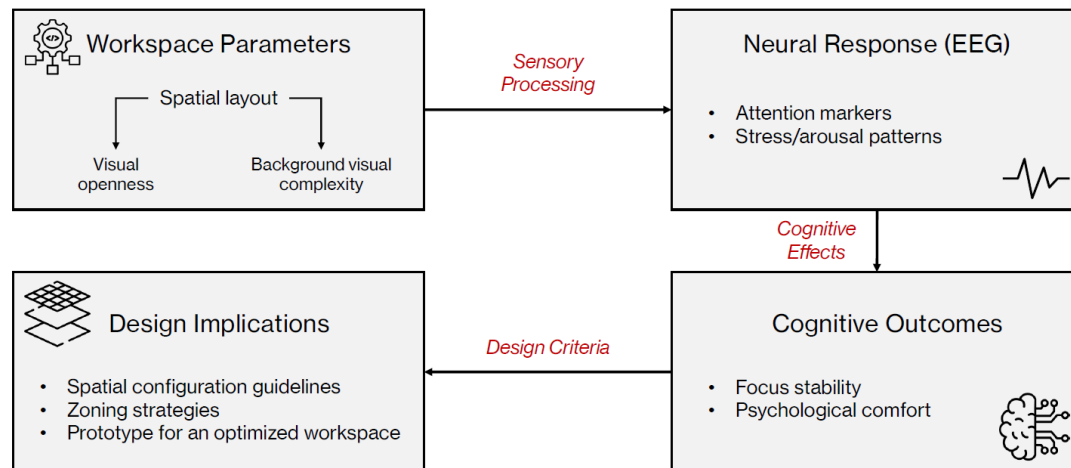


Figure 1.4: Relationship between workspace layout variables, neural responses, cognitive outcomes, and resulting design implications. Source: [Author].

1.5 Research content

This study aims to bridge the gap between neuroscientific theory and architectural practice and is structured into eight key phases. Chapter 1 identifies the scope of the problem, tracing the crisis in contemporary workspaces and exploring the potential of neuroarchitecture before formulating the experimental hypotheses.

Having established the premises, Chapter 2 outlines the methodological design. It explains in detail how the selected spatial parameters, namely Visual Openness and Perceived Complexity, were isolated and measured through the simultaneous use of Mixed Reality headsets and electroencephalography.

Before advancing to the experimental phase, defining the test context was essential. Chapter 3 focuses on the 'La Nave' building, located within the university campus of the Cravino Pole in Pavia. This provides a practical analysis of Giancarlo De Carlo¹'s work, identifying the spatial framework that forms the basis for the virtual simulations.

Chapters 4 and 5 detail the core of the experimental procedure. After defining the

¹ Giancarlo De Carlo (1919-2005), one of the most important Italian architects, urban planners and theorists of the second half of the twentieth century, was part of Team 10 and was a pioneer of participatory architecture. Known for his ability to rigorously combine technical and aesthetic aspects with the social approach of architectural work, his notable international interventions include the University Pole of Pavia, which originated in the 1970s, the University Colleges of Urbino, and the intervention in the center of Urbino.

four distinct architectural layouts, the study transitions into the Mixed Reality testing phase, where participants explored the environments while their neurophysiological arousal and proxemic stress were continuously monitored.

Chapter 6 is dedicated to data analysis. It examines the statistical and biometric results obtained from the EEG recordings, rigorously evaluating the validity of the hypotheses formulated at the beginning of the study.

Chapter 7 presents the practical design outcome of the thesis. The statistical results are translated into a specific Evidence-Based Design application aimed at retrofitting Floor G of “La Nave”. By introducing the transparent cellularity paradigm and parametrically validating the layout through Isovist and Edge Density calculations, the chapter demonstrates how spaces can be redeveloped based on the actual cognitive needs of their users.

Finally, the thesis concludes with Chapter 8, which provides a summary of the findings and the responses to the research questions. This is followed by a critical assessment of the research limitations regarding the investigated environmental variables, ultimately outlining future development paths to further explore the relationship between spatial design and objective measurement.

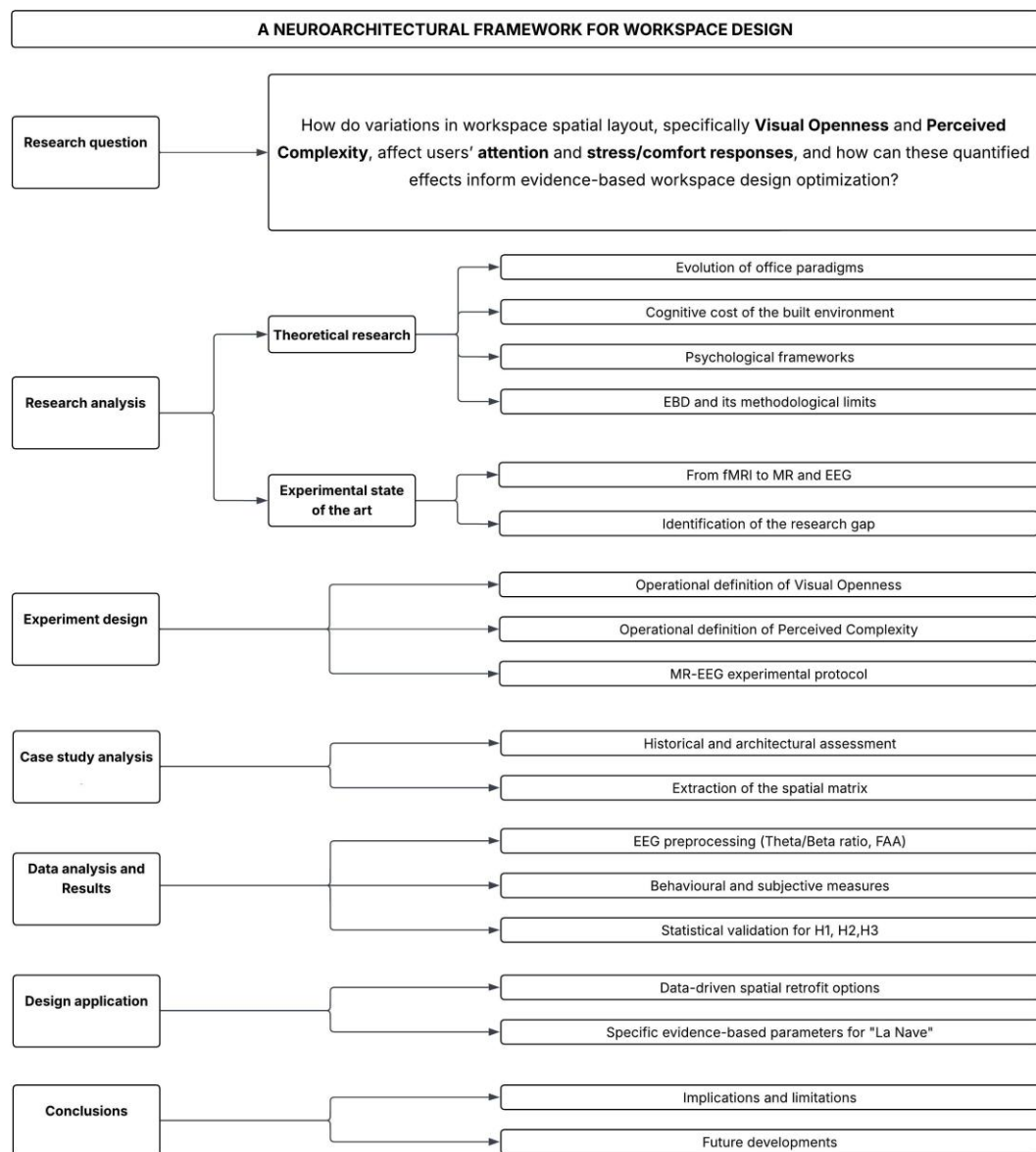


Figure 1.5: Methodological flowchart illustrating the logical structure of the thesis. Source: [Author].

2. THEORETICAL FOUNDATION AND STATE OF THE ART

2.1 The evolution of workspace: from Taylorism to neuroarchitecture

To understand the reasons behind the shift toward a neuroarchitectural approach, it is necessary to analyse the evolution of each architectural paradigm. At the beginning of the 20th century, the design of workspaces was strongly influenced by



Figure 2.1: The Larkin Administration Building, designed by Frank Lloyd Wright (1904). The orthogonal arrangement of desks reflects the mechanistic approach of Taylorism, functioning as a managerial panopticon. Source: [Collection of The Buffalo History Museum. Larkin Company photograph collection].

the theories of Scientific Management, developed by Frederick Winslow Taylor. This period saw the assimilation of the industrial logic of the assembly line into interior architecture, conceiving the workspace as a machine and the worker as an interchangeable gear (Saval, 2014). The primary goal of this approach was to optimize procedural efficiency through a rigorous process of visual hierarchization. While functional for the repetitive manual tasks of early industrialization, this model proved structurally inadequate for the knowledge economy. Contemporary work constitutes an intensely cognitive activity. Consequently, Taylor's spatial legacy fails to accommodate the neurobiological requirements of modern knowledge workers, necessitating a scientific shift towards cognitive ergonomics.

A paradigmatic example of this approach is the Larkin Administration Building, designed by Frank Lloyd Wright in 1904 (Figure 2.1). Despite its advanced use of natural light and ventilation, the spatial layout functioned as a managerial panopticon

(Duffy, 1997). Workers, arranged in a grid-like layout, were constantly under the visual surveillance of their superiors. Within this mechanistic design framework, ergonomics was studied exclusively in biomechanical terms, without considering the cognitive load caused by the lack of spatial privacy.

The first challenge to the rigidity of Taylorism in Europe came between the late 1950s and early 1960s with the implementation of the *Bürolandschaft* (Office Landscape) by the German consulting firm Quickborner Team (Figure 2.2). This design team, composed of Eberhard and Wolfgang Schnelle, proposed a radical departure from the orthogonal grid through the concept of organic offices in which the arrangement of furniture is based on communication flows and workers' paths (Saval, 2014). The removal of physical barriers aimed to democratize the workspace; concurrently, it introduced foundational vulnerabilities regarding sensory overload.

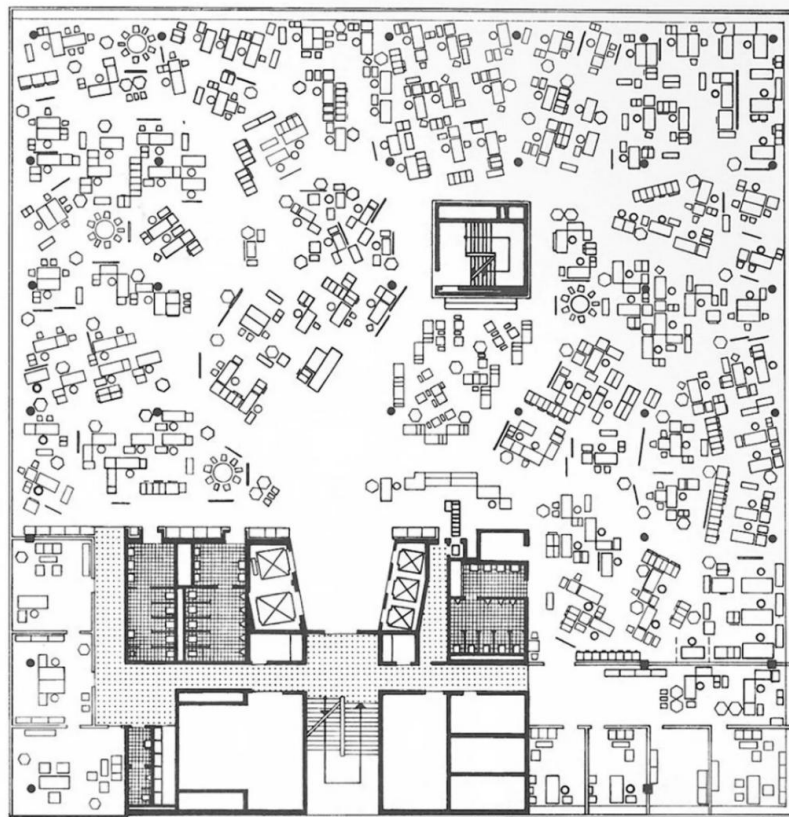


Figure 2.2: Osram Offices, Quickborner, Munich, 1963. A typical layout of a Bürolandschaft (Office Landscape) where the organic arrangement of desks was designed to reflect communication flows rather than hierarchy. Source: [Walter Henn and Henn Architects]

At the same time, in the United States, the need to find a balance between socialization and concentration led designer Robert Propst to create the Action Office (1964) for the Herman Miller company. The initial idea was revolutionary for its

modernity, offering knowledge workers a dynamic environment that allowed postural variations and guaranteed a degree of visual privacy through movable partitions (Saval, 2014). However, the logic of cost savings and real estate standardization soon pushed American companies to fix flexible partitions, fitting as many desks as possible into the minimum area, thereby giving rise to the infamous Cubicle Farms (cubicle barrier) (Figure 2.3) (Duffy, 1997). This architectural degeneration led to the failure of the organic and rational illusion of office, reducing the workspace to a standardised module. This often aroused feelings of alienation and sensory isolation, without effectively protecting against acoustic interference (Sundstrom et al., 1994; Kim & De Dear, 2013).



Figure 2.3: The degeneration of the organic workplace. (A) The original Action Office, designed by Robert Propst for Herman Miller (1964), intended to provide knowledge workers with flexible, dynamic environments, varied postures, and calibrated visual privacy. (B) A typical Cubicle Farm from the late 20th century. Driven by real estate cost-saving logic, corporate management rigidly standardized Propst's flexible partitions, enclosing workers in tight, orthogonal modules. This evolution marked the failure of spatial autonomy, generating profound sensory isolation. Source: [K2space].

In response to the claustrophobic conditions of cubicles, a further significant shift in how people perceive the workplace began in the 1990s with the rise of the open-plan office model. In this regard, the absence of internal partitions in the workplace has been promoted and legitimized by corporate executives and architectural professionals as a catalyst for serendipity, transparency, and collaboration among office employees (Allen & Henn, 2007; Duffy, 1997). However, a substantial body of scientifically valid literature has emerged that challenges the narrative of office architecture. Analyses of POE questionnaires have consistently shown that the expected benefits of increased interaction are frequently outweighed by a significant decrease in environmental satisfaction, primarily related to the lack of visual and acoustic privacy (Kim & De Dear, 2013). Furthermore, the absence of physical partitions in the workplace forces individuals to be exposed to constant and irrelevant stimuli, which negatively affects cognitive performance (Banbury & Berry, 2005; Seddigh et al., 2015). Epidemiological analyses confirm a significant correlation between density in an open-plan office environment and increased rates of stress, absenteeism, and Sick Building Syndrome (SBS), in contrast to traditional cellular environments (Danielsson & Bodin, 2008; Pejtersen, Allermann, Kristensen, & Poulsen, 2006).

In a context aimed at reducing the critical issues related to open-plan while maintaining the relative effectiveness of real estate optimization, the current paradigm has oriented attention towards *Activity-Based Working* (ABW). This model, based on hot-desking, an office design system that uses desks as workstations that are used by different people at different times on an ad hoc basis, and the absence of fixed-position occupancy, allows workers to choose among different functional microenvironments according to their tasks (Appel-Meulenbroek, Groenen, & Janssen, 2011). While providing spatial flexibility, ABW introduces a severe cognitive cost, frequently underestimated by conventional architectural metrics. The frequent renegotiation of one's position leads to decision fatigue, which erodes a sense of territoriality, a fundamental human psychological construct (Hoendervanger, de Been, Van Yperen, Mobach, & Albers, 2016; Morrison & Macky, 2017). The inhibition of territorial control and depriving the individual of a safe proxemic refuge contradicts the primordial evolutionary needs theorized by *Prospect-Refuge Theory* (Appleton, 1975). For this reason, these environments activate neurophysiological responses of chronic arousal and spatial anxiety, potentially hindering access to states of deep

concentration.

The growing awareness of these historical failures highlights the ontological limitations of conventional office architecture, which traditionally evaluated spatial performance based on economic criteria (density, flow efficiency) or subjective post-occupancy reports. This trajectory necessitates a definitive paradigm shift towards cognitive ergonomics and neuroarchitecture (Figure 2.4). By translating the neural dynamics of attention and stress into computable architectural parameters, workspace design can evolve from a densification tool into an infrastructure of cognitive support.

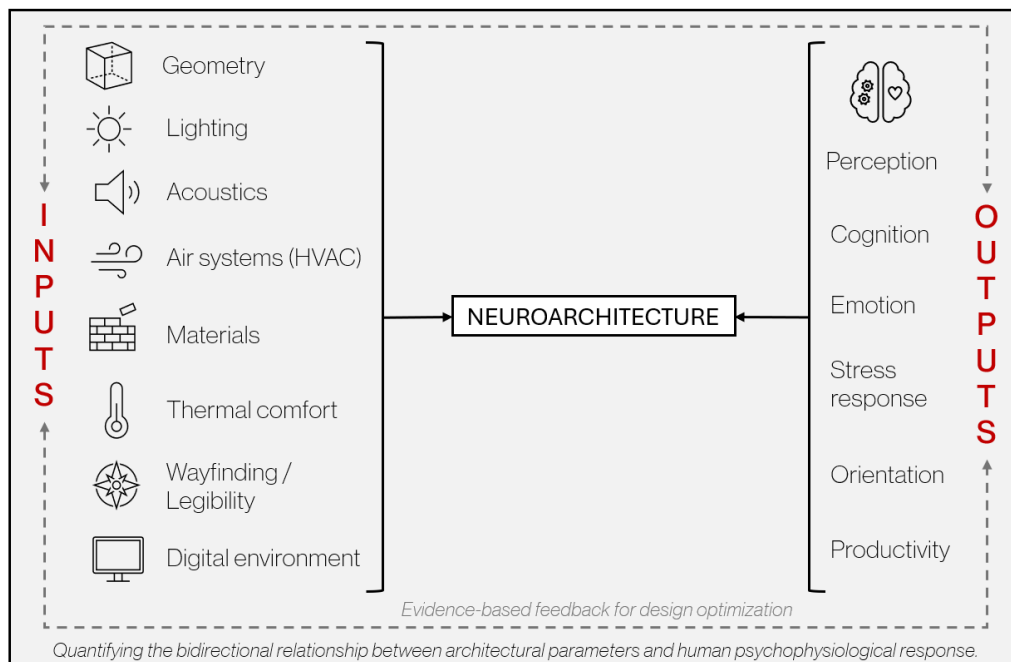


Figure 2.4: Diagram illustrating the relationship between architectural parameters (inputs) and human psychophysiological responses (outputs) within the neuroarchitectural framework. Source: [Author].

2.2 Psychological frameworks for spatial design

To transform the identified critical issues in workspaces into controllable architectural variables, it is necessary to frame the project within theoretical frameworks that scientifically define the link between cognitive processes and the environment. Three theoretical contributions are of great interest to this research: Kaplan's *Attention Restoration Theory*, Appleton's *Prospect-Refuge Theory*, and Berlyne's *Arousal Theory*. In the present thesis, these frameworks are used strictly as interpretive references to support the selection of architectural variables and

neurophysiological biomarkers, rather than as theories being directly and fully tested in their entirety.

2.2.1 Attention Restoration Theory (ART)

Rachel and Stephen Kaplan's *Attention Restoration Theory* (ART) distinguishes between directed attention, which is voluntary and cognitively demanding, and forms of involuntary attention associated with stimuli that engage interest effortlessly, a condition described as soft fascination (Figure 2.5). In cognitively intensive work contexts, the first attentional system is engaged over prolonged periods to filter out distractions, inhibit irrelevant stimuli, and maintain attentional focus on the task. This often results in directed attention fatigue, which manifests as reduced concentration, irritability, and decreased performance (R. Kaplan & Kaplan, 1989).

Within the ART framework, environmental quality depends not only on the reduction of disturbance but also on the extent to which a setting supports the recovery of directed attention. In this thesis, ART is therefore not treated as a theory to be tested in its entirety, but as a psychological framework that helps interpret whether specific spatial conditions are more likely to support or deplete attentional resources. From this new perspective, subjective self-assessments alone are not sufficient to describe attentional states with adequate resolution. For this reason, the present thesis complements psychological interpretation with neurophysiological indicators used as empirical proxies of attentional effort and restoration, rather than as direct or exhaustive measurements of the theory itself. Earlier interpretive models frequently associated generalized attentional states with the Theta/Beta Ratio as a marker of working memory load; recent research suggests that this index may be less specific to working memory load than previously assumed, and may instead reflect broader attentional fluctuations, including spontaneous mind-wandering (Kiiski et al., 2020). Accordingly, this thesis adopts Event-Related Synchronization and Desynchronization (ERS/ERD) patterns as neurophysiological indicators through which sustained attentional effort may be examined during cognitively demanding activities. In EEG analysis, ERS refers to an increase in rhythmic neural activity, whereas ERD refers to a reduction in rhythmic power, both of which are commonly interpreted in relation to task engagement and cortical processing demands. In the present study, directed attentional effort is examined through EEG patterns including frontal theta synchronization (4-8 Hz), commonly associated with executive demand, and parietal

alpha desynchronization (8-12 Hz), often interpreted as reflecting sustained visuospatial and attentional allocation (Gevins & Smith, 2003; Raufi & Longo, 2022). Taken together, these indicators provide a time-sensitive neurophysiological basis for interpreting variations in attentional demand across different architectural configurations.

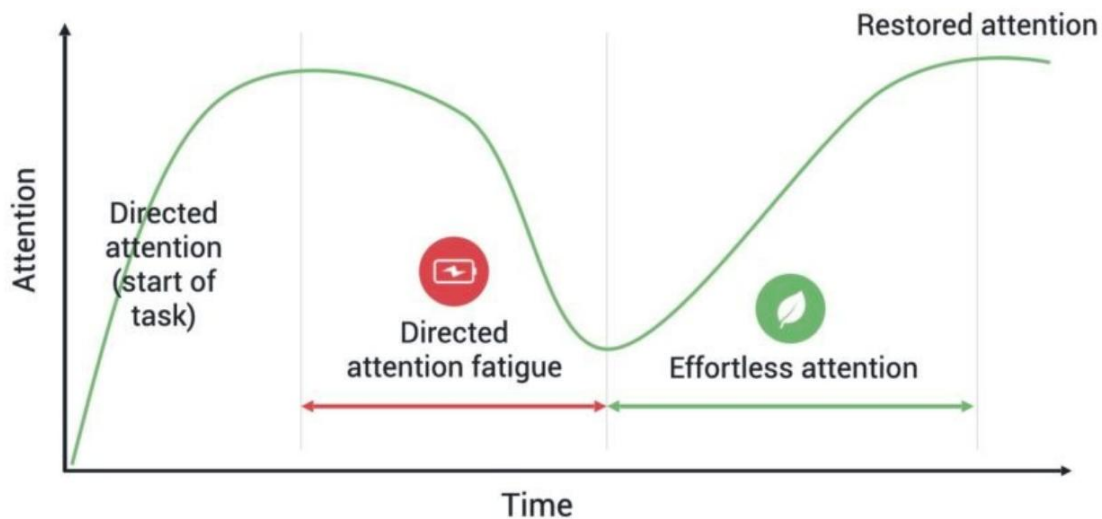


Figure 2.5: Conceptual model of Attention Restoration Theory (ART). The diagram illustrates the depletion of directed attention during cognitively demanding tasks and its potential recovery through effortless attention associated with soft fascination. Source: [CATS-Cambridge-Newsletter, 12th May 2023].

2.2.2 Prospect-Refuge Theory

To understand why some spatial configurations are more stressful, it is necessary to examine human preferences considering primary adaptive mechanisms. In 1975, geographer Jay Appleton developed the *Prospect-Refuge Theory*, according to which humans seek environments that allow the simultaneous experience of the Prospect, or the ability to see from a wide vantage point to monitor threats, and the Refuge, referring to the provision of physical or perceived enclosure, often from behind, which minimizes exposure and enhances the perception of safety (Figure 2.6) (Appleton, 1975).

When applied to the contemporary work environment, this theory elucidates the crisis of the open-plan model. In this context, Prospect results from an overall condition of visual openness that simultaneously reduces Refuge, a dynamic hypothesized to induce states of sustained arousal or hypervigilance. More

importantly, this creates a need for a fundamental reassessment of this condition within the context of modern Activity-Based Working and fluid spatial exploration (e.g., standing desks or active MR navigation). When an individual assumes a standing posture, the visual horizon exceeds conventional low partitions (1.2 m), thus significantly expanding Prospect. Concurrently, however, this posture leaves the body more exposed, substantially reducing the perceived physical Refuge that the seated position might afford. The current study aims to investigate this specific condition of heightened spatial vulnerability, as constant exposure to others' gaze may foster a latent desire to withdraw from the work environment.

To empirically examine the behavioural impulse associated with this spatial vulnerability, the present study employs Frontal Alpha Asymmetry (FAA) as a neurophysiological proxy. FAA is a well-established EEG metric associated with emotional valence and approach-withdrawal motivation (Davidson, 1992; Harmon-Jones, Gable, & Peterson, 2010). Specifically, the FAA measures the difference in alpha band activity between the right and left hemispheres of the prefrontal cortex. Relatively greater activation of the right prefrontal cortex is commonly interpreted in the literature as an indicator of withdrawal motivation and negative affective responses to environmental stimuli (Briesemeister, Tamm, Heine, & Jacobs, 2013), making it a suitable metric for assessing the impulse to avoid uncomfortable spatial configurations.

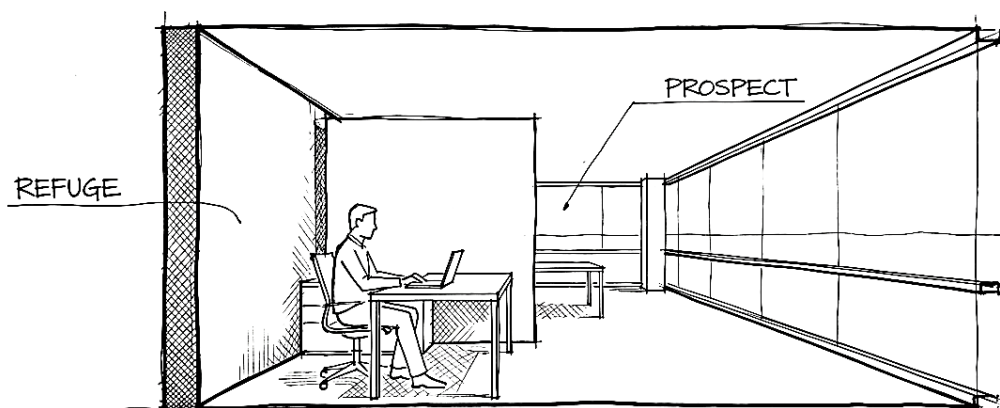


Figure 2.6: Conceptual architectural sketch illustrating the Prospect-Refuge Theory (Appleton, 1975). The worker's position balances physical protection from behind (Refuge) with an unobstructed visual field for environmental monitoring (Prospect). The current study investigates how this balance is disrupted when transitioning to a standing, active posture. Source: [Author].

2.2.3 Arousal Theory

While it is true that visual openness influences the development of a sense of security, levels of architectural detail modulate nervous system activation. *Arousal Theory*, developed by psychologist Daniel Berlyne (1971), posits that hedonic preference and physiological arousal in response to visual complexity follow an inverted U-shaped pattern. Although visual complexity is often mistakenly understood as a synonym for decorative disorder and overload of furnishings, the present research operationalizes complexity strictly as the topological and morphological articulation of the architectural envelope. Spatially rigid and orthogonal environments may cause sensory deprivation (hypo-stimulation), while highly irregular geometries, with non-orthogonal angles and fragmented subdivisions, saturate perceptual processing (measurable through Edge Density), potentially leading to cognitive overload and stress regardless of furnishings. Cognitive well-being is found at the central peak of this curve, in an optimal zone of stimulation (Figure 2.7).

Following the general model developed by Berlyne, which postulates the existence of a continuous spectrum of complexity, the present architectural study focused on the two diametrically opposite poles of the topological spectrum to elicit a measurable neurophysiological response. By contrasting the purely orthogonal layout, which corresponds to the hypo-stimulation baseline, with a highly fragmented non-orthogonal layout, which corresponds to the overload threshold, the study aims to investigate the physiological responses at these theoretical extremes of spatial cognitive load within the tested experimental conditions.

Thus, the introduction of Perceived Complexity as the second independent variable in the experimental protocol stems from the need to assess the complexity of the built environment rigorously. Consequently, the joint application of architectural algorithmic analyses and EEG allows for an Evidence-Based Design approach to investigate how workspace geometry modulates cognitive load, indexed by Frontal Theta synchronization and Parietal Alpha desynchronization, and spatial stress or avoidance motivation, reflected in FAA variations.

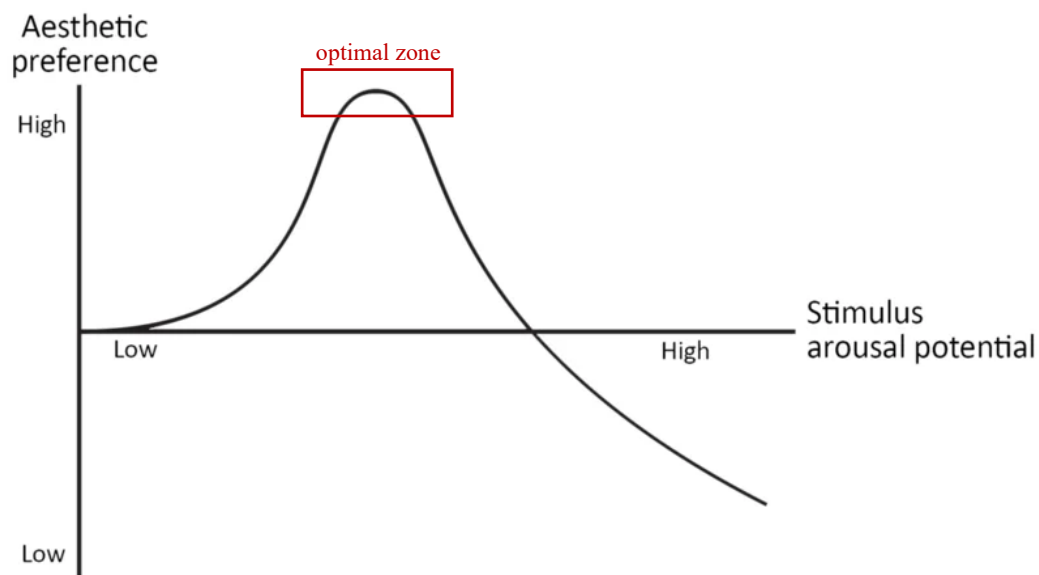


Figure 2.7: The Inverted-U relationship between visual complexity and aesthetic preference, based on Berlyne's Arousal Theory (1971). The model illustrates that cognitive well-being and positive hedonic responses are achieved at intermediate levels of environmental complexity, avoiding both sensory deprivation and cognitive overload. Source: [DOI: <https://doi.org/10.31234/osf.io/t98kv>].

2.3 Evidence-Based Design (EBD)

Increased awareness of the cognitive and physiological impacts of the built environment has made a critical reconsideration of traditional design methodologies inevitable. Relying solely on the architect's aesthetic intuition, or the exclusive application of calculable indices to optimize space consumption, now appears insufficient, and potentially ethically questionable, in the context of a design for human well-being. This awareness led to the transposition of a stringent yet rigorous protocol from the clinical sciences into the architectural field, known as Evidence-Based Design (EBD).

2.3.1 Medical genesis: the clinical impact of space

Evidence-Based Design develops from its epistemological roots in Evidence-Based Medicine (EBM), a paradigm based on the need to integrate the best available scientific research into healthcare professionals' decision-making processes. In the architectural context, the decisive historical moment that sanctioned the need

for this new paradigm can be identified in Roger S. Ulrich's pioneering study (1984), published by the American Association for the Advancement of Science (AAAS) in the journal *Science*. The researcher empirically demonstrated, by analysing hospital records, that patients recovering from general surgery in rooms with windows overlooking natural landscapes had a shorter postoperative course, and had to take much lower doses of narcotic analgesics than patients whose windows faced a brick wall. Ulrich's study represented a conceptual watershed. Thereafter, spatial and visual configuration was no longer considered merely a neutral background but was objectively measured as an active therapeutic factor.

2.3.2 Definition and methodological rigour

From its pioneering applications in *Healthcare Design*, EBD has expanded to include work, educational, and residential design. Hamilton and Watkins (2009, p. 9) formally define Evidence-Based Design as “a process for the conscious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project”. It is therefore not a limitation on the architect's creativity, but a methodological choice to embrace a hypothetical-deductive approach to design. The architect adopting EBD is required to formulate specific research questions before design, find validated answers to these questions in the scientific literature, transform these answers into specific design guidelines, and subject these answers to rigorous post-occupancy testing. In this approach, a building is considered a materialized scientific hypothesis.

3. METHODOLOGY

3.1 Introduction

This chapter outlines the methodological framework designed and developed to empirically test the hypotheses formulated in Chapter 1. In keeping with the interdisciplinary nature of neuroarchitecture, the research is based on a 2x2 within-subjects factorial matrix that manipulates Visual Openness (VO) and Perceived Complexity (PC) through controlled Mixed Reality (MR) simulations. The methodological choices described below are specifically tailored to capture neurophysiological responses to spatial layout variations during an active, standing exploration of the workspace.

The research methodology is divided into sequential phases (Figure 3.1). Section 3.2 defines the research design and the factorial matrix used to isolate the independent variables. Section 3.3 describes the measurement of the spatial variables of VO and PC in four digital scenarios using the structural grid of the “La Nave” building in Pavia as a reference matrix. Section 3.4 describes the participants' sampling strategy and the selection criteria applied. Section 3.5 describes the technological setting of the experiment, namely the MR and EEG equipment, as well as the spatial exploration task designed to examine users' neurophysiological responses to moving around in different workspaces. Section 3.6 details the psychometric assessment, while Section 3.7 outlines the experimental procedure step by step. Section 3.8 describes the data observation and qualitative analysis required to evaluate the cognitive effects of architectural variations and support the development of design guidelines based on scientific evidence.

METHODOLOGICAL WORKFLOW

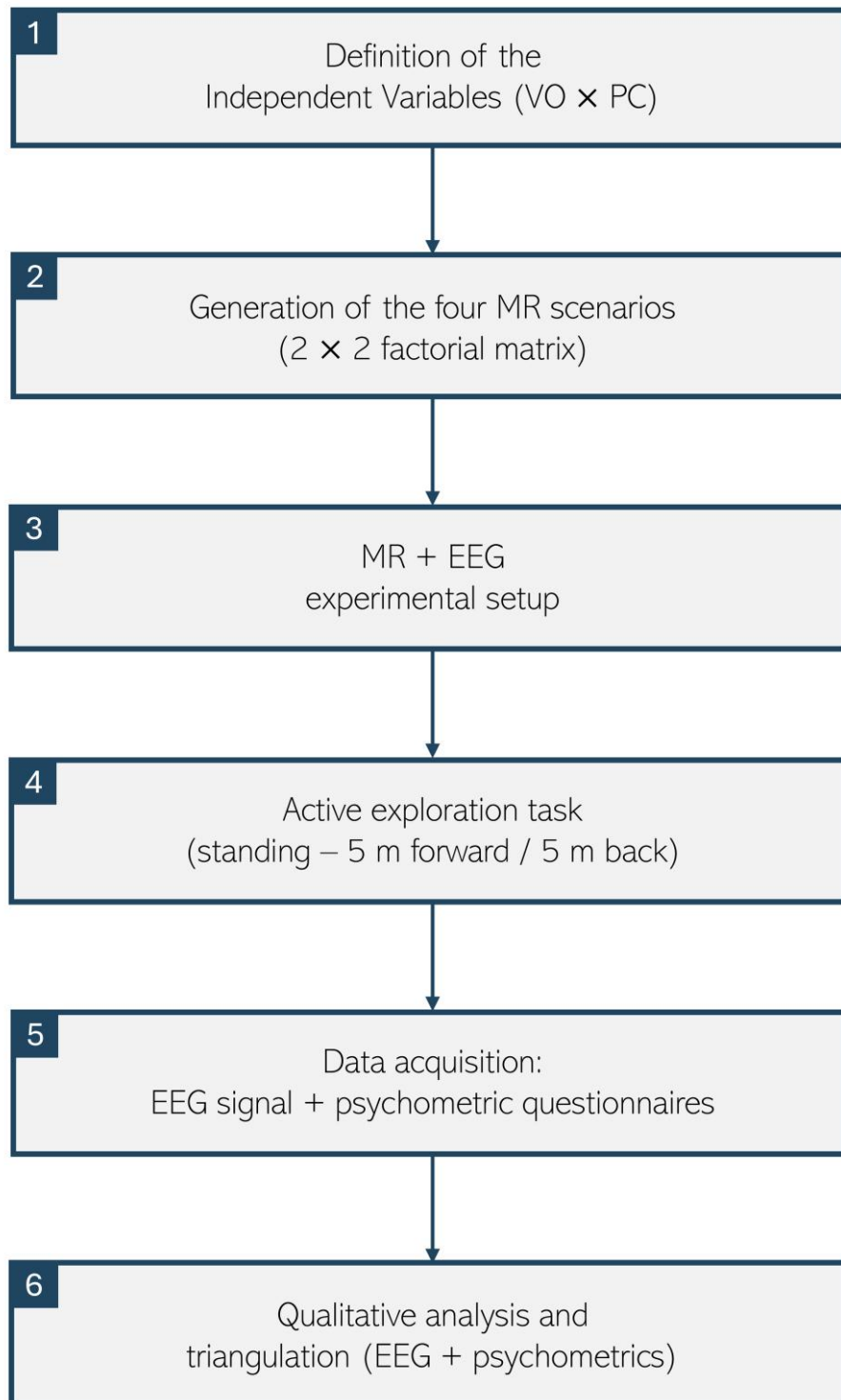


Figure 3.1: Synoptic overview of the methodological workflow, from the definition of the independent variables to the qualitative triangulation of EEG and psychometric data. Source: [Author].

3.2 Research design

The aim of this research was therefore to isolate and qualitatively assess the neurophysiological effects of a specific workspace spatial morphology, thereby overcoming the subjective biases inherent in the use of POE questionnaires. To address the research question and test the proposed hypotheses (H1, H2, H3), a 2x2 within-subjects factorial experimental design with repeated measures was employed. The two selected independent variables (IV) were visual openness (VO) and perceived complexity (PC) in the architectural environment. These two variables were each dichotomized into two levels of spatial intensity: Low and High. This yields a matrix of four distinct architectural scenarios: Low VO-Low PC, Low VO-High PC, High VO-Low PC, and High VO-High PC. (Figure 3.2)

The use of a repeated-measures design, in which the same participants were exposed to all four scenarios, is a fundamental methodological requirement in electroencephalography research (The Oxford Handbook of Event-Related Potential Components, 2012). Neural responses exhibit considerable interindividual variability. Therefore, the use of the repeated-measures approach ensures that each participant serves as a control for themselves. This effectively controlled for inter-individual differences, allowing observable changes in Frontal Theta and Parietal Alpha activity patterns, as well as proxemic stress (FAA), to be attributed to the controlled exploration of the four architectural conditions (Figure 3.3).

To ensure the scientific rigor of the test while maintaining the ecological validity of the experience, the experiment was conducted using MR technology. This technology allowed the four virtually created spatial scenarios, defined based on the morphological matrix of “La Nave”, to be overlaid onto a physical environment and workstation, with participants standing and freely exposed to the surrounding space. In this way, a rigorous standardization of environmental disturbance factors, such as lighting and acoustics, was made possible, introducing the geometric-visual configuration of the space surrounding the user as the sole active factor. Consequently, this setup enabled an accurate measurement of involuntary neurophysiological responses to changes in the architectural envelope.

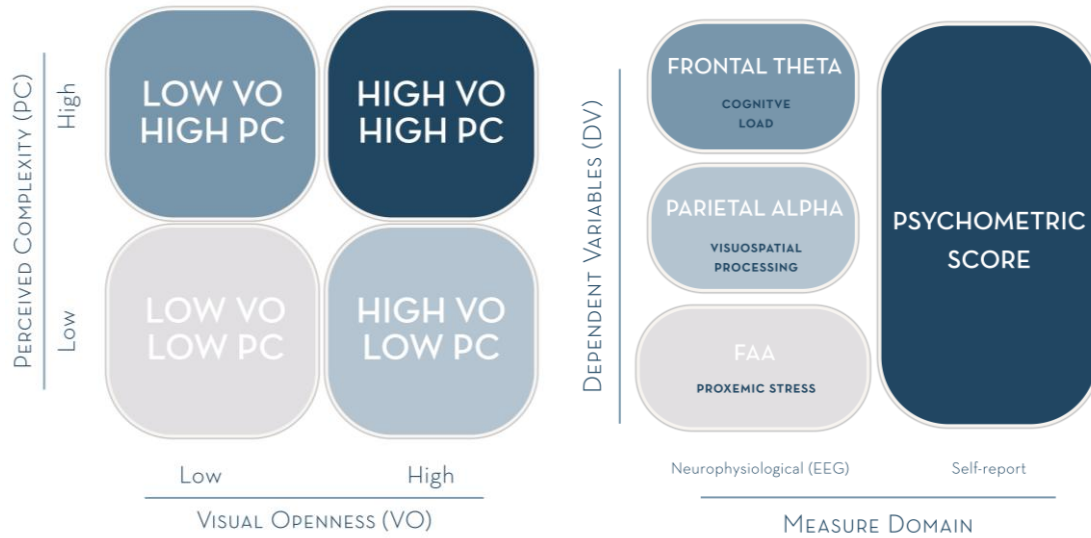


Figure 3.2: Conceptual matrix of the 2x2 within-subjects factorial design, illustrating the four experimental Mixed Reality scenarios defined by the intersection of the Independent Variables (ID): Visual Openness (VO) and Perceived Complexity (PC). Source: [Author].

Figure 3.3: Dependent Variables (VD) of the study, grouped by measure domain (neurophysiological / self-report). Divided into Frontal Theta (cognitive load), Parietal Alpha (visuospatial processing), FAA (proxemic stress), and self-report. Source: [Author].

3.3 Operational definition of the architectural variables

For maximum methodological rigour and exact replication of the experiment, the independent architectural variables must be removed from any heuristic-qualitative evaluation. The psychological constructs explored in the theoretical framework require rigorous spatial operationalisation. At this stage, the distribution scenario is not evaluated in terms of aesthetic and functional parameters but is broken down into scalar quantities extracted algorithmically from three-dimensional models. This rigorous quantification is performed before real-time projection of the layouts into the MR headset.

3.3.1 The morphological matrix: “La Nave” (floor G)

To ensure that the virtual scenarios presented to participants possess a high degree of architectural realism, these 3D spaces were not conceived as arbitrary abstract volumes. Instead, the structural layout of the “La Nave” building, and more specifically the area of this structure housing the offices on floor G, served as a fixed morphological template for the experimental configuration. Although Chapter 3

3.METHODOLOGY

provides a detailed analysis of Giancarlo De Carlo's work from a historical and architectural perspective, at this methodological stage, the building functions strictly as a geometric constraint. The static structural elements, such as the grid of load-bearing columns, the central distribution core, the glazed perimeter walls, and the height of the suspended ceilings, define a morphological bounding box within which all four experimental layouts are modelled (Figure 3.4). Within this invariant boundary, only the internal partition system is reconfigured to generate the controlled variations of the independent variables VO and PC, thereby maintaining genuine physical constraints and maximising the ecological validity of the neuroarchitectural simulation.

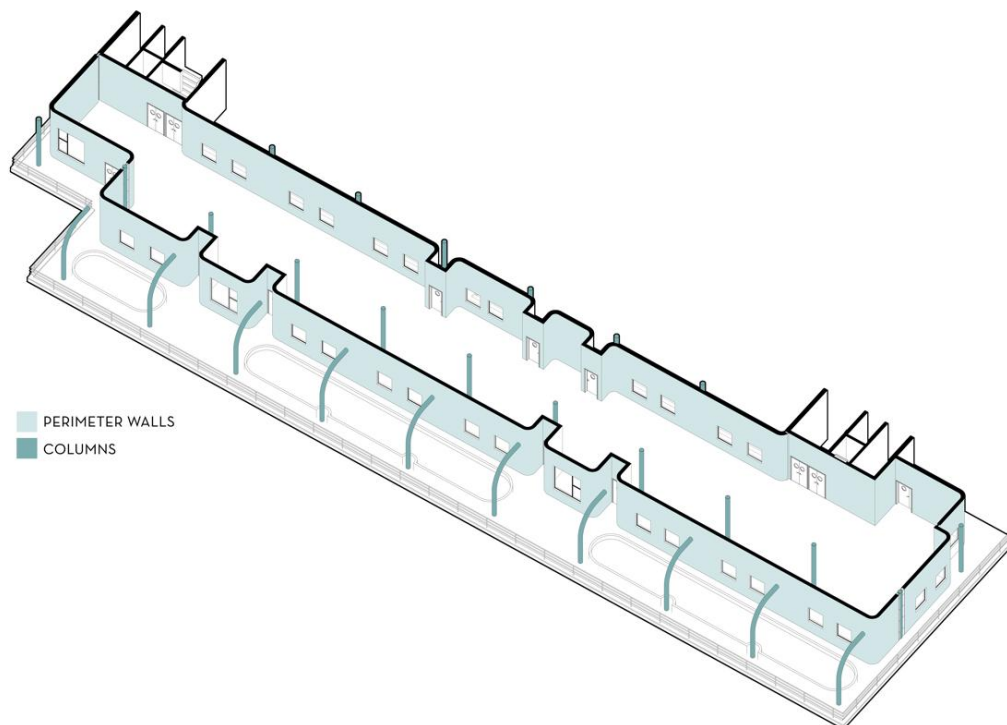


Figure 3.4: The static morphological bounding box of “La Nave” (floor G). The structural grid and perimeter boundaries act as an invariant geometric constraint across all experimental scenarios, ensuring the ecological validity of the simulation. Source: [Author].

3.3.2 Parametric computation of Visual Openness (VO)

To objectively quantify the balance between spatial exposure and the perception of shelter, the VO variable was operationalised in accordance with the principles of Isovist Analysis. At a theoretical level, the isovist is defined as the set of all and only the points in space visible from a given Vantage Point (VP), circumscribed only by the opaque surfaces of the built environment (Benedikt, 1979).

For the experimental application, the procedure of calculating isovists was carried out using the advanced spatial analysis software package *isovist.org* (Figure 3.5). To ensure ecological validity for the simulation, for each scenario, three viewpoints (VP) were positioned along the route of the predicted exploration path. The placement of VP was at an elevation on the z-axis equal to 1.65 m above ground level, which corresponds to the average height of an adult eye in an upright position during dynamic spatial exploration.

From each VP, the program generates a closed polygon at 360 degrees on the horizontal plane. From this geometry, two main metrics were automatically extracted by the program:

1. **Area of isovist (A_{iso}):** This metric determines the degree of visual exposure (Prospect). A high value of A_{iso} denotes the maximum degree of visual exposure characteristic of open spaces (High VO).
2. **Isovist perimeter and Occlusivity (O_{iso}):** measured in linear meters. Using models from evolutionary psychology, Appleton's (Appleton, 1975) shelter theory can be translated into spatial boundaries; that is, a high percentage of solid, enclosed perimeter in relation to the visual area indicates a high degree of physical protection (Low VO).

The final VO metrics for each architectural scenario (Low VO and High VO) have been calculated by averaging the values of Area and Occlusivity across the three VP, thus ensuring a solid parametric representation of the spatial experience along the entire walking path.

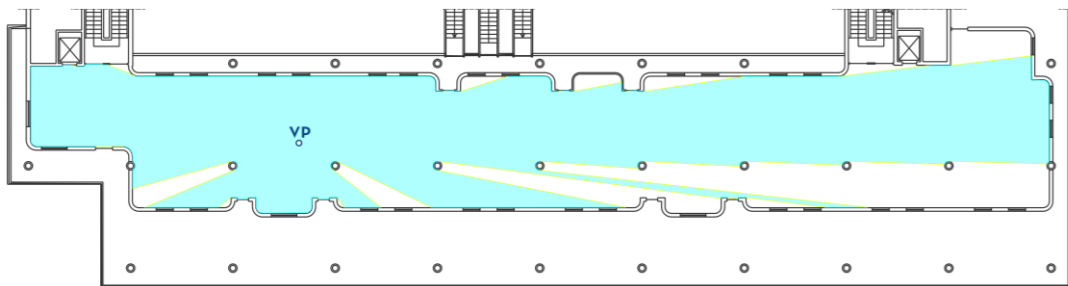


Figure 3.5: Example of algorithmic extraction of Visual Openness (VO) using isovist analysis. The coloured polygon represents the 360-degree visible area from a predefined Vantage Point (VP) set at eye level (1.65 m) along the exploration path. Source: [Author].

3.3.3 Algorithmic extraction of Perceived Complexity (PC)

The variable PC, related to visual information overload and associated neural activation (Arousal), eludes planimetric analysis. To operationalise it, the research employed advanced Computer Vision methodologies, based on the calculation of Edge Density (ED). This metric is based on neurobiological evidence that the visual cortex decodes the complexity of a scene by measuring the spatial frequency of high-frequency contrast gradients, that is, the structural edges of objects (Machado et al., 2015; Stamps, 2002).

The computational process consisted of two strictly defined phases. Initially, first-person perspective projections were extracted from the 3D models. To ensure consistency along the exploration path, three virtual cameras (VPs) were positioned at a height of 1.65 m for each scenario. The virtual cameras were calibrated with an 18 mm focal length (yielding an approximate horizontal Field of View of 90°). This parameter effectively approximates the primary human visual cone during locomotion without introducing extreme wide-angle distortion that would artificially multiply the perception of edges at the periphery of the image.

Although human spatial experience involves multiple senses and is influenced by lighting, colours, materials, and furnishings, geometry forms the basis of architectural interior design. Spatial geometry determines the shape, size, and motion constraints within space. For this reason, edge detection was performed using highly standardized and static inputs to isolate geometric from visuo-material variables. To control the effects of spatial geometry and avoid any possible visual interference in the EEG signal, all material and illumination variations were intentionally excluded from this methodological step. The three-dimensional models used in the edge detection process were made using Lambertian (grey) surfaces, free of any form of furniture. This action was necessary to ensure that neurophysiological data and edge density calculations reflected only the intrinsic geometric complexity of architectural space. The integration of material and aesthetic dimensions is intentionally reserved for the applied design phase, addressed in Chapter 7.

Finally, the output pixel matrices were processed using the algorithm developed by Canny (Canny, 1986) for edge detection (Figure 3.6). Feature extraction is achieved through a sequence of three processes: filtering, gradient calculation, and hysteresis thresholding. The resulting dataset represents the spatial configuration in binary form, where edges are represented by white pixels and the resulting voids by

black pixels.

The perceived complexity of a scene is objectively determined by the following formula (Machado et al., 2015):

$$ED\% = \left(\frac{\Sigma E}{W \times H} \right) \times 100$$

Where the nomenclature indicates:

- ΣE : The total sum of edge pixels (white pixels) identified in the binary image.
- W : Width of the original image measured in pixels.
- H : Height of the original image measured in pixels.
- $W \times H$: The product that returns the total number of pixels in the visual scene.

The PC of each case was calculated by taking the mean value of the Edge Density (ED) measure for all three images created for each case.

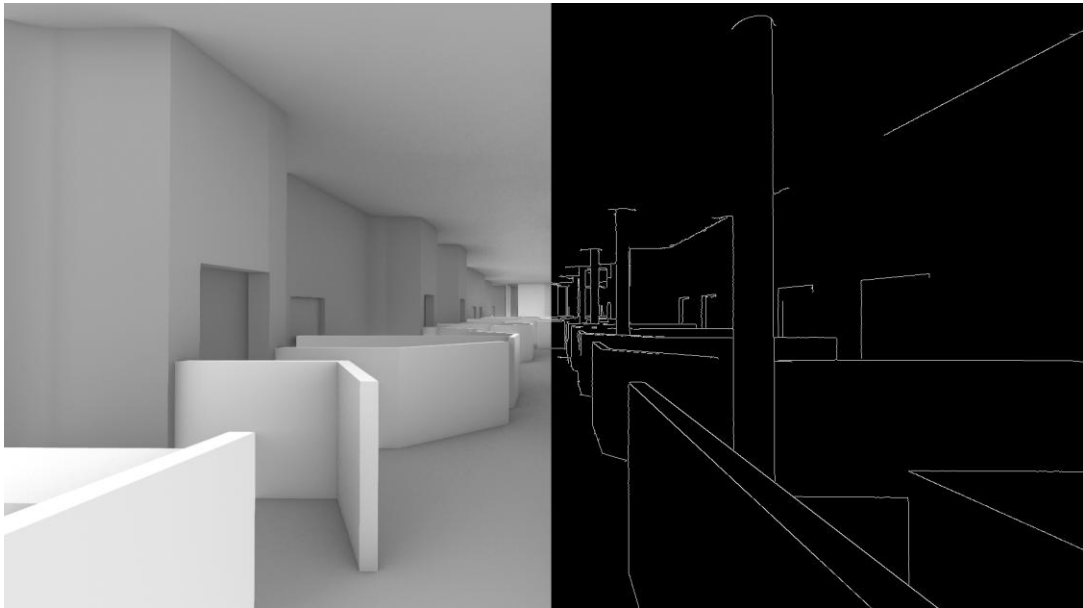


Figure 3.6: Algorithmic extraction of Perceived Complexity (PC). Left: the 3D perspective rendered with uniform Lambertian surfaces to exclude material interference. Right: the same scene processed via the Canny edge detection algorithm to isolate high-frequency contrast gradients (Edge Density). Source: [Author].

3.4 Participants

To examine the neurophysiological responses to spatial variations defined by the independent variables, a **pilot study** involving 20 participants was conducted. This is in line with the requirements of neuroarchitectural research using the mobile EEG method in the context of extended reality environments, where validation of the method and calibration of the instrumental setup are the primary research objectives (Banaei et al., 2017).

Regarding the participants to be recruited for the study, the sampling strategy consisted of recruiting volunteers through convenience sampling from among young adults (e.g., university students and early-career knowledge workers). Although the participants were not necessarily the actual users of the ‘La Nave’ case study, this demographic group was considered adequate for investigating basic neurophysiological reactions to spatial layout variations in office-like environments. The present methodological phase aims to capture generic patterns of arousal and proxemic stress elicited by different configurations of enclosure and geometry complexity. Their neurophysiological responses to spatial load can therefore be interpreted as indicative of how human users react to such architectural manipulations.

To ensure the integrity of the neurophysiological signal and minimise potential anatomical biases, strict inclusion and exclusion criteria were applied. Given that the experimental protocol was based on the measurement of Frontal Alpha Asymmetry (FAA) for the observation of proxemic stress, only strongly right-handed subjects, previously assessed using the Edinburgh Handedness Inventory (Oldfield, 1971), were included in the study. Left-handed and ambidextrous subjects were excluded from the study, as this was mandatory for the present methodological phase, given that the lateralisation of frontal brain functions differs significantly in these subjects, compromising the comparability of the spatial biomarker (Grimshaw & Carmel, 2014). Other requirements included normal or corrected-to-normal vision, as well as the absence of neurological disorders or the use of psychoactive medications that could alter the EEG trace (Figure 3.7). All participants provided written informed consent before the start of the sessions, in accordance with the ethical principles outlined in the Declaration of Helsinki.

PARTICIPANT INCLUSION CRITERIA

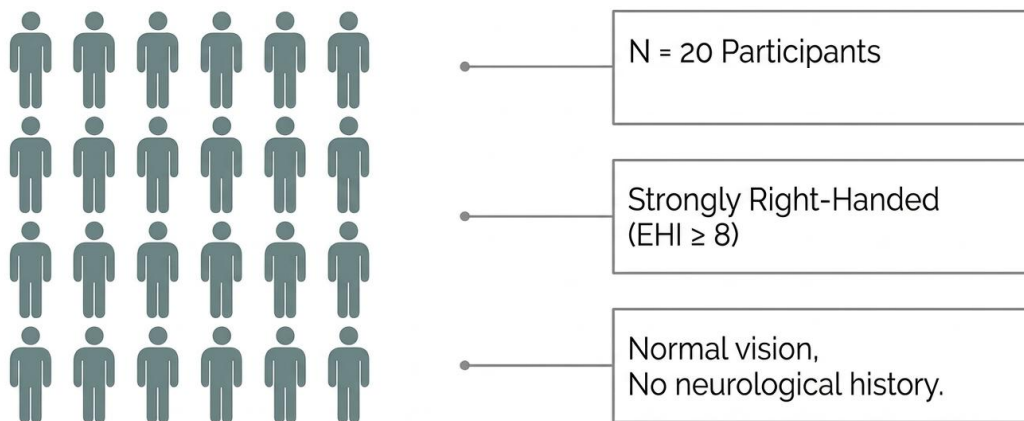


Figure 3.7: Summary of the participant inclusion criteria. The study included 20 master's students in Architecture. Selection required strong right-handedness (Edinburgh Handedness Inventory score of 8 or higher), normal vision and no previous neurological history. Source: [Author].

3.5 Experimental methodology (MR-EEG protocol)

To objectively investigate the cognitive effects induced by the spatial variations described above, an experimental protocol was developed that combines architectural simulation in Mixed Reality (MR) with continuous neurophysiological recording (EEG).

3.5.1 Equipment

The architectural stimuli were delivered via the Meta Quest 3 headset. Unlike other Immersive Virtual Reality (IVR) devices, where the user is completely isolated from the external environment, the Meta Quest 3's colour passthrough technology made it possible to see the participant's body and the real physical floor, onto which the scenarios generated in Rhinoceros were superimposed like a large-scale architectural hologram. This visual anchoring to the real environment is crucial for dynamic exploration tasks, as it ensures natural visual-motor coordination during walking, guarantees physical safety by preventing collisions, and prevents cybersickness.



Figure 3.8: The experimental apparatus employed in the study, comprising the Meta Quest 3 Mixed Reality (MR) headset for virtual spatial simulations, the Emotiv EPOC X wireless Electroencephalography (EEG) headset for real-time neurophysiological data collection and the ZED 2i AI STEREO Camera. Source: [Author].

At the same time, for the recording of the neurophysiological signal, the Emotiv EPOC X mobile EEG device was used, namely a 14-electrode wireless EEG headset equipped with saline-soaked felt pads to minimize skin impedance and ensure high signal quality without using invasive gels which made it possible to record the natural electrical signal from the human brain at a sampling rate of 128 Hz (Figure 3.9). The electrodes were positioned according to the international 10-20 system. This layout allows for the correct mapping of the frontal area (specifically AF3, AF4, F3, F4), useful for monitoring visible asymmetries indicative of FAA as a marker of proxemic stress, and for tracking Frontal Theta synchronization associated with cognitive load. Furthermore, it ensures the coverage of the parietal area (P7, P8) necessary for observing patterns of Parietal Alpha desynchronization, while the occipital sensors (O1, O2) monitor general visual activation.

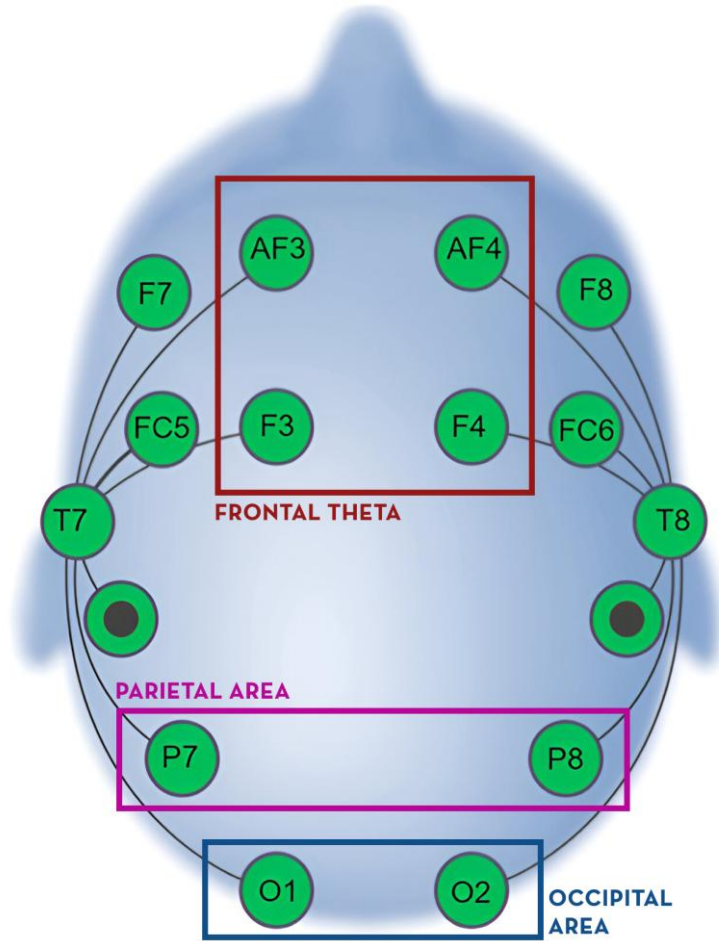


Figure 3.9: Topographic layout of the 14-channel Emotiv EPOC X headset according to the international 10-20 system. The prefrontal (AF3, AF4) and frontal (F3, F4) clusters are highlighted, as they serve as primary regions of interest for monitoring Frontal Alpha Asymmetry (FAA) and Theta synchronization. Source: [Author].

3.5.2 The space exploration task

The experimental task was designed to simulate an active and natural exploration of the virtual scene, where the subject had to perform real movements. In the case of MR scenarios, an attempt was made to model the transition movements typical of open-plan and Activity-Based offices. Participants needed to adhere to a predefined linear path, walking 5 meters forward and backward. The goal was to replicate the type of natural spatial navigation that people undertake when moving from one workspace to another. Participants had to mimic realistic spatial navigation within the virtual architecture superimposed onto the physical laboratory space. This dynamic approach ensured authentic visuomotor coordination and allowed for the evaluation of neurophysiological responses to changes in spatial geometry (VO and PC) exclusively

during active transition movement, decisively distinguishing this study from the evaluation of stationary desk work.

3.6 Psychometric assessment

To triangulate the observed neurophysiological data and rigorously measure the psychological effect of each of the scenarios, a psychometric instrument was developed, distributed and completed by the participants after exploring each of the environments. The questionnaire was structured on a 7-point Likert scale (with a score between 1 = "Strongly disagree / Very low" and 7 = "Strongly agree / Very high"), grouped into four thematic sections. Specifically, all questions were adapted based on theoretical frameworks validated in the literature to assess specific constructs related to individual-space interaction:

1. **Spatial presence** (adapted from the Igroup Presence Questionnaire - IPQ): The first section assessed the effectiveness and ecological validity of Mixed Reality's environment. The items, including sense of being there, spatial realism, and isolation, helped assess how participants experienced immersion and presence in the virtual office.
2. **Environmental assessment** (based on the Kaplan & Kaplan framework): The second section investigated the perception of spatial morphology. The items were formulated to assess complexity (the density of distinct architectural components), coherence (the logical order of partitions), legibility or wayfinding (ease of navigation), and a sense of mystery (the desire to further explore the place).
3. **Cognitive load and stress** (adapted from NASA-TLX): The third section was intended to assess the mental effort and directional fatigue experienced by participants while exploring each layout. It is based on the NASA Task Load Index (TLX), one of the best-known and most validated tools in the field of cognitive ergonomics, used to quantify workload. The section assessed mental demand, effort, and perceived frustration (e.g., confusion or irritation). These parameters serve as a fundamental psychological equivalent for triangulating the activation variations of the Frontal Theta and Parietal Alpha EEG waves.
4. **Behavioural intent**: The final section presented an indicator focused on

real-world application (workplace feasibility), in which subjects were asked to assess the suitability of a specific design layout to perform their tasks within a realistic physical office environment effectively.

This tool has allowed for the collection of reliable subjective indicators, which are essential for corroborating and contextualizing the measurement of neurophysiological indicators.

3.7 Experimental procedure

The experimental sessions were conducted individually within the controlled laboratory environment. Upon arrival, each participant was informed of the study objectives and provided written consent (the Appendix contains an original white copy of the consent form). The procedural sequence consisted of EEG setup, software calibration, and subsequent iterative exposure to the spatial scenarios, followed immediately by the experimental task and psychometric evaluation.

The preparation phase began with the setup of the EEG Emotiv EPOC X mobile device. The felt pads of the 14 electrodes were adequately hydrated with saline solution to ensure maximum skin conductivity. After ensuring a stable connection between the device and the computer, the helmet was applied to the participant's head. A rigorous software calibration procedure was then performed to ensure the correct allocation of sensors following the international 10-20 system and that the signal transmission quality reached an optimal level on all relevant channels.

Once the technical preparation phase was completed, the active experimental phase began. According to the structured cycle of operations described below, each participant was subjected to iterative exposure to four architectural scenarios:

1. The participant wore the MR Meta Quest 3 headset, where the virtual space environment was initialized (superimposed on the physical space of the laboratory)
2. The participant completed the dynamic exploration task (walking 5 meters forward and 5 meters backward).
3. At the end of the crossing, the participant removed the headset.
4. The participant completed the psychometric questionnaire described in the previous section (paragraph 3.6) to record the immediate subjective perception of the space just explored.

5. This procedural sequence (MR exposure, dynamic exploration, psychometric assessment) was repeated to conduct the assessment of all four planned scenarios.

3.8 Data observation and qualitative analysis

In line with the ecological and exploratory nature of the pilot study conducted, the data analysis focused on a qualitative and observational approach with respect to the development of statistically quantitative models. The choice of the active exploration paradigm (standing and moving) allows for maximum experimental ecological validity. However, it intrinsically introduces a greater susceptibility of the EEG signal to motor and muscle contamination than classical reference protocols, conducted within the framework of sedentary EEG modelling. Due to motion artefacts in MoBI EEG, the analysis focuses on macro-patterns rather than statistical inference.

From this methodological perspective, the main objective of EEG analysis was to identify neural activation macro-patterns through direct viewing of signals in response to architectural variations. An attempt had been made to highlight:

- **Visible Frontal Theta synchronization and Parietal Alpha desynchronization patterns**, recognized as indicators of increased cognitive and visuospatial effort. Monitoring these patterns is crucial to ascertain whether spatial transitions impose additional Directed Attention Fatigue (DAF) between work sessions, rather than assuming such transitional spaces inherently restore attention.
- **Asymmetry in Alpha band activity between the frontal hemispheres (FAA)**, used as a neurophysiological marker of approach-avoidance motivation and proxemic stress.

To ensure maximum scientific robustness to these observations and compensate for the noise generated by MoBI measurements, it was necessary to resort to a data triangulation approach. The phenomenological trends observed in EEG tracings during spatial transitions were systematically compared with psychometric data obtained from post-exploration tests (paragraph 3.6). This combined methodological approach allowed us to validate the measurements, obtaining a holistic and reliable understanding of how spatial morphology modulates neurophysiological arousal and user cognitive comfort.

4. CASE STUDY: NEUROARCHITECTURAL ANALYSIS OF FLOOR G (LA NAVE AT CRAVINO CAMPUS IN PAVIA)

4.1 Site analysis: Giancarlo De Carlo's "La Nave" at Cravino Pole (Pavia, Italy)

The empirical validation of the proposed neuroarchitectural framework requires a well-defined and quantifiable morphological matrix. For this reason, the selected case study is the "La Nave" building, located within the Cravino Pole campus of the University of Pavia. To clarify the spatial and institutional relevance of this choice, a preliminary analysis of local context and of Giancarlo De Carlo's original design concept is first required. For this study, the building is not analysed as an architectural artifact per se, but as a morphological system providing geometric constraints for experimental modelling.

4.1.1 The local context

The intervention area is located in Pavia (45°12' N, 9°08' E) (Figure 4.1), in the Lombardy region of northern Italy, about 35 km south of Milan. From an urban perspective, Pavia is characterized by a compact historical fabric, whose development remained closely tied to its consolidated urban core for centuries. In the twentieth century, population growth and the development of large institutional activities led to gradual expansion beyond the historic center toward the outskirts.

In this context, the northwestern part of the city, in particular the area known as Cravino, became a suitable site for large university and scientific activities owing to the greater availability of land and its relative detachment from the constraints of the historic urban structure. (Delsante, 2007).



Figure 4.1: Pavia, Italy - 1:20,000 scale adapted. Source: [Author].

4.1.2 Giancarlo De Carlo's concept

Within this larger urban context, the University of Pavia entrusted architect Giancarlo De Carlo with drafting the "Development and Restructuring Plan of the University of Pavia". Launched in 1970 and officially concluded in 1974, the plan aimed to redefine the relationship between the academic institution and the surrounding urban fabric (Prina, 2023). Contrary to the traditional Anglo-Saxon model of the closed university campus, conceived as an entity independent of the surrounding urban context, De Carlo advocated a multipolar structure for the university. From this perspective, the central core and the new peripheral poles had to be interconnected through a continuous spatial and functional network (MiC, 2024).

In this project context, the Cravino area, which at the time had an agricultural vocation, was designated as a new hub for scientific and technological activities within the university. The master plan called for the creation of an open campus, organically organized to house technical and scientific faculties (Engineering, Mathematics, Biological Sciences, and Pharmacy) (Figure 4.2). A key element of the project was the idea of an academy that would not function as an exclusive enclave. The plan, in fact, included a central service section and commercial facilities, fully accessible and usable even by residents, thus establishing a symbiotic relationship between students and citizens (De Carlo et al., 1977; Lombardia Beni Culturali, 2014).

However, historical and architectural literature highlights a marked discrepancy between original intentions and built reality. The construction phase of the Cravino Pole, carried out mainly between 1972 and 1985, was strongly influenced by structural delays, modifications during construction and financial constraints. As a result, the multipolar system remained partially implemented and the integration of public spaces and services was never fully achieved according to the indications of the original masterplan (Lombardia Beni Culturali, 2014).

Within this broader strategy, the “La Nave” building became a key morphological node of the Cravino Pole, functioning both as a structural artefact and as a contemporary workspace (Figure 4.3).

The choice of the "La Nave" building as a key site for analysis in the proposed neuroarchitectural research can be explained by several rigorous methodological and historical arguments. Methodologically, the process of testing an Evidence-Based Design (EBD) approach using a pilot project would necessarily require a high degree of ecological validity. Given that the MR-EEG experiments involved participants from the case study context, it makes sense to conduct them in a familiar spatial context to reduce the risks of potential bias in the form of cultural differences. Architecturally, applying contemporary neuroarchitectural parameters to De Carlo's structuralist framework creates a highly relevant dialogue between 20th-century sociological architecture and 21st-century cognitive ergonomics. Furthermore, the rigid structural grid of the building provides a clear boundary condition of morphological invariance, which facilitates the control of internal geometric variables, such as Visual Openness and Perceived Complexity, without modifying the overall macrostructure.

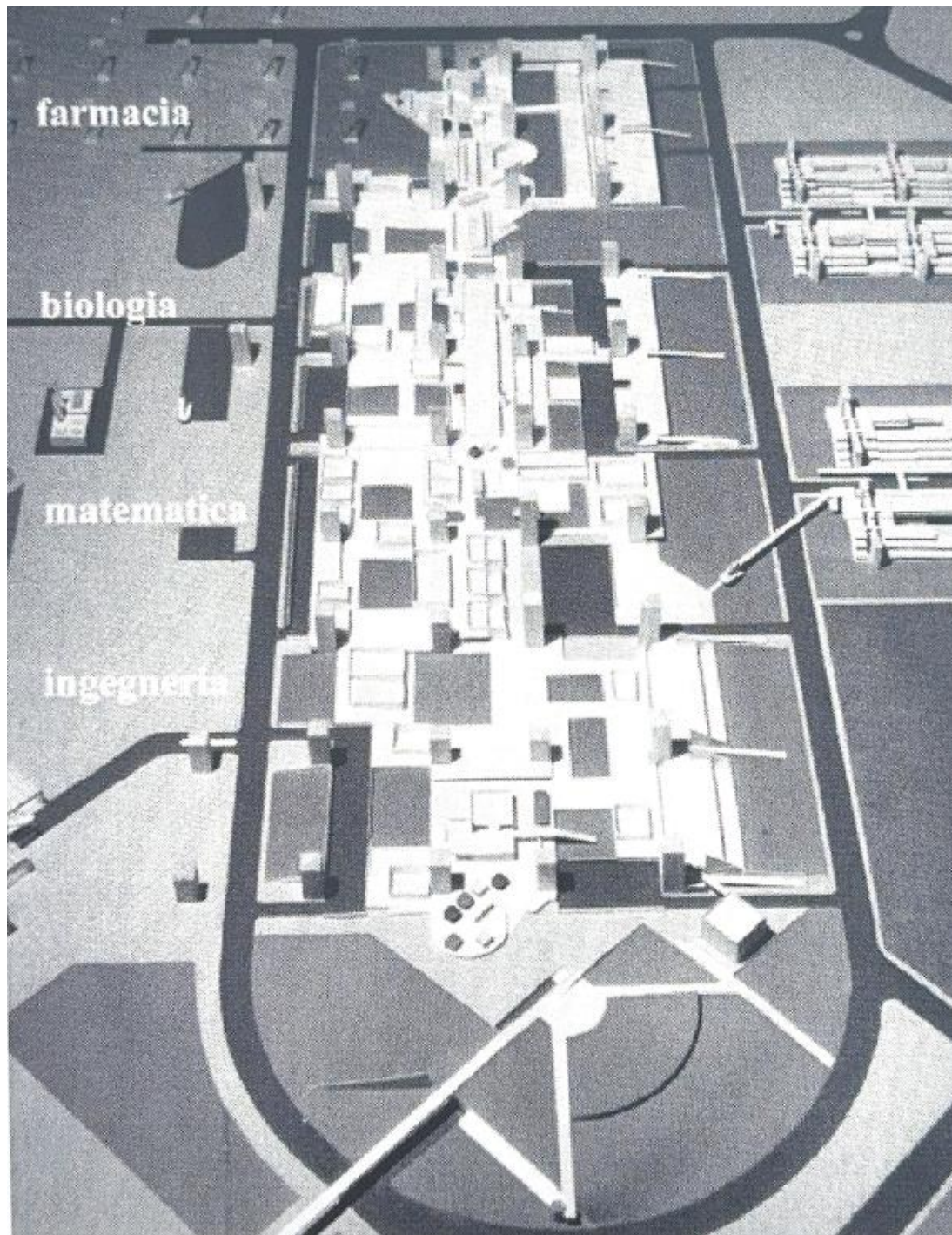


Figure 4.2: The Cravino scientific pole in Pavia. The original masterplan as envisioned by Giancarlo De Carlo.
Source: [Giancarlo De Carlo and the faculty of engineering of Pavia, 2012].

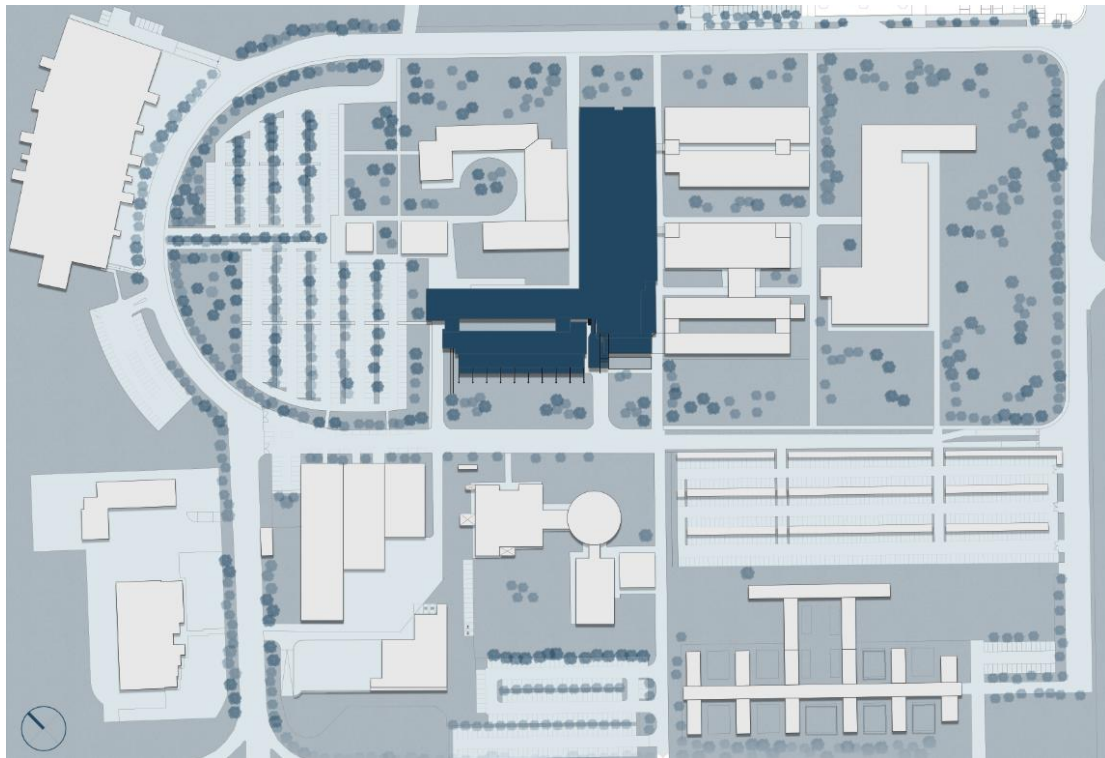


Figure 4.3: Current masterplan of the Cravino scientific pole in Pavia. Source: [Author].

4.1.3 The current spatial configuration and floor G

To translate De Carlo's urban planning objectives into a concrete experimental model, it is necessary to analyse the tectonic and distributional properties of the building currently housing the Faculty of Engineering, commonly known as "La Nave" for its ship-like composition with staggered floors and porthole windows.

From a construction point of view, and as documented in Lombard historical sources, "La Nave" operates according to a strict principle of modularity. The building is organised by an intersecting system of two structural grids: a larger one, whose nodes host the vertical circulation cores, and a smaller one, corresponding to the pitch of the exposed steel load-bearing structure (Lombardia Beni Culturali, 2014). The main blocks consist of double parallel volumes, organized on staggered floors of half a level and separated by an open central space. This immutable metallic structural matrix defines the structural framework of the present research, outlining the physical and volumetric constraints within which floor G is analysed.

Within this structural framework, the layout of floor G, selected as the empirical focus of this research, exhibits a marked spatial densification (Figure 4.4). This floor

4.CASE STUDY: NEUROARCHITECTURAL ANALYSIS OF FLOOR G (LA NAVE AT CRAVINO CAMPUS IN PAVIA)

houses the administrative offices and workstations of the teaching staff, featuring a cellular layout dominated by partitions and a single main distribution corridor. Parametrically, this morphology is hypothesized to induce a high level of visual occlusion (Low Visual Openness), which suppresses lateral peripheral vision and forces users into a narrow, highly canalised field of view along the corridor (Prospective).

At the same time, the continuous fragmentation of spaces produced by internal partitions, broken orthogonal alignments and an abundance of visual obstacles theoretically generate a high level of environmental complexity (High Perceived Complexity), saturating the scene with contrast gradients (high Edge Density).

From a neuroarchitectural perspective, this specific combination of high visual occlusion and geometric density makes floor G an ideal environment to investigate the psychophysiological cost of architectural space. Active spatial exploration of a highly canalised layout requires continuous visual-spatial processing effort, inducing measurable levels of spatial arousal and proxemic stress that can be captured through electroencephalography analysis.

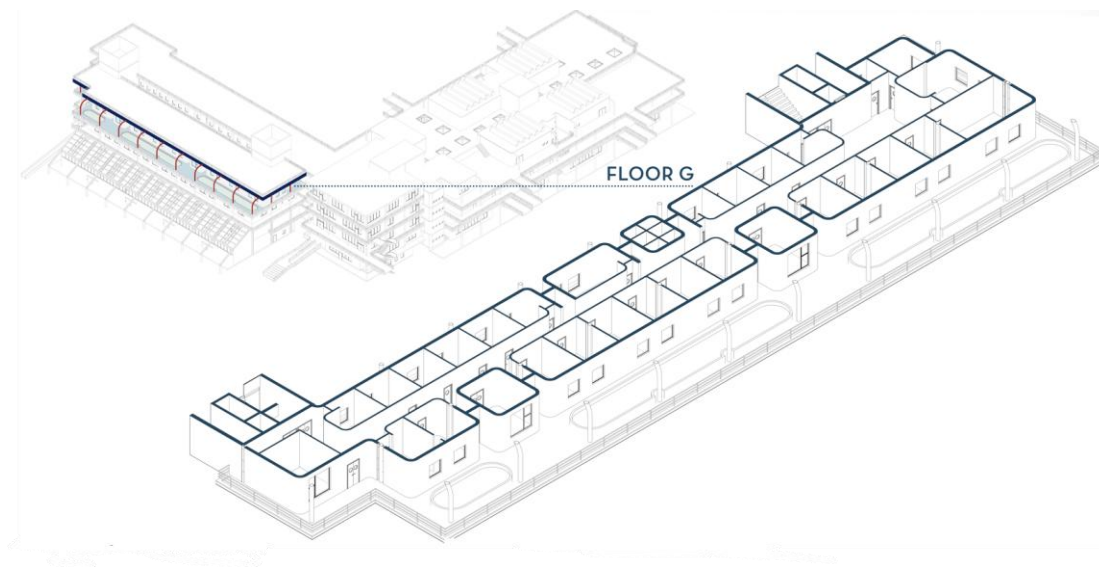


Figure 4.4: Current layout of floor G. Source: [Author].

4.1.4 Quantitative spatial analysis of the existing configuration

To empirically anchor the qualitative reading presented in §4.1.3, the two independent variables, Visual Aperture (VO) and Perceived Complexity (PC), were considered and measured for the actual configuration of Floor G according to the metric extraction protocol to be used in parametric scenarios (Chapter 5).

To quantify VO, an isovist analysis was performed on the two-dimensional model of the central corridor, established as the main distribution element of the plane. Three viewpoints (VP) were defined along the longitudinal axis of the corridor at a height of 1.65 m from the floor, according to the protocol described in §3.3.1. For each of the three VPs, all relevant isovistic parameters were extracted: area, perimeter, occlusiveness, compactness, drift, and mean visual depth (Table 4.1; Figure 4.5). The three viewpoints returned extremely homogeneous results (mean area = 1.732 m²; mean perimeter = 17.581; mean occlusivity = 0.374), meaning that the corridor axis is characterized by a completely regular horizontal section. Specifically, the limited isovist area and high occlusiveness provide the quantitative measure of the visual canalization and lateral closure condition already qualitatively discussed in §4.1.3. Finally, the low mean value of visual depth (1.969) suggests that the corridor axis is characterized by a low depth of visual perception.

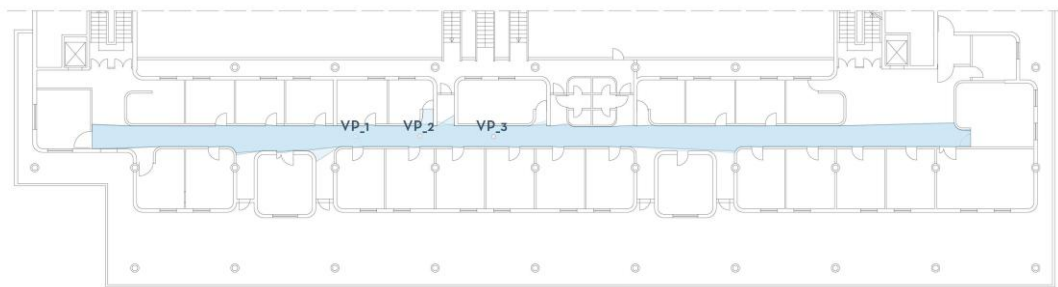


Figure 4.5: Isovist analysis of the existing configuration of floor G. Source: [Author].

Ref	x	y	Sweep	Heading	Range Far	Range Near	Drift	Area	Occlusivity	Vista	Perimeter	Compactness	Overt Control	Covert Control	CoVisibility	Choice	Mean Visual Depth
1	27,341	13,135	360	180	82	0	1,514	1,722	0,373	5,750	17,371	0,072	41,904	1,091	1,665	0,712	1,965
2	32,076	13,135	360	180	82	0	1,169	1,724	0,382	5,389	17,455	0,071	45,265	1,082	1,659	0,712	1,976
3	37,057	13,135	360	180	82	0	0,907	1,749	0,366	5,127	17,916	0,068	54,070	1,056	1,640	0,712	1,965
Mean values								1,732			17,581						1,969

Table 4.1: Isovist analysis of the existing configuration of floor G.

4.CASE STUDY: NEUROARCHITECTURAL ANALYSIS OF FLOOR G (LA NAVE AT CRAVINO CAMPUS IN PAVIA)

PC quantification is performed by applying the Canny edge detector to a photographic image of the corridor captured from the front, along the longitudinal axis of the corridor (Figure 4.6). The threshold and Gaussian filtering parameters correspond to those set for parametric scenario analysis (see the script in Appendix B). The calculation result is an image characterized by an edge density of 3.23% (edge pixels = 61,970 / total pixels = $1,920 \times 1,080$; Table 4.2). This value represents the global effect of the inhabited field of view, including the non-architectural geometric elements present in the corridor (such as doors, signage, lighting fixtures, skirting boards, reflections, and material breaks). From an interpretative point of view, the result confirms the condition of high perceived complexity hypothesized in §4.1.3, since the perceptual saturation of the visual field experienced by the observer while crossing the corridor is reflected in the high-density index of the edges.



Figure 4.6: Edge density analysis of the existing configuration of floor G. Source: [Author].

VP	Pixel tot. (1920x1080)	Edge pixels	Edge density (%)
1	1,920.000	61.970	3,2276

Table 4.2: Edge Density analysis of the existing configuration of floor G.

Taking both metric indicators into account, a unique configuration can be outlined relating to the condition of the G-plane corridor: a space that appears strongly closed laterally and channelled (Low VO, reduced and highly occluded isovist) and with a high density of edges in the inhabited field of view (High ED). In this way, the

proposed characterization allows us to confirm in quantitative terms what was discussed qualitatively in §4.1.3 and to obtain the empirical reference of the existing configuration, from which to start in the tests of Chapter 5.

4.2 Functional assessment of floor G

4.2.1 Existing layout and workspace organization

According to the analysis of floor G, the planimetric configuration reveals a spatial layout with a strong hierarchical stratification, in which the circulation system is strictly aligned with the original structural layout of the "La Nave" building. The space is organised around a single central corridor, which constitutes the primary circulation axis from which the individual functional units branch out. These spatial units take the form of cellular offices that accommodate teaching and administrative staff.

Morphologically, the offices are enclosed volumes of different sizes (approximately between 10 and 25 square meters), delimited by full-height opaque partitions (Figure 4.7). The central corridor functions as a residual, enclosed space, bounded by long continuous walls that are only punctuated by the entrances to the individual offices. Although the comb-like arrangement maximizes circulation efficiency and ensures acoustic insulation for the individual rooms, it reduces the corridor to a mere functional duct, completely devoid of decompression spaces or intermediate resting areas.

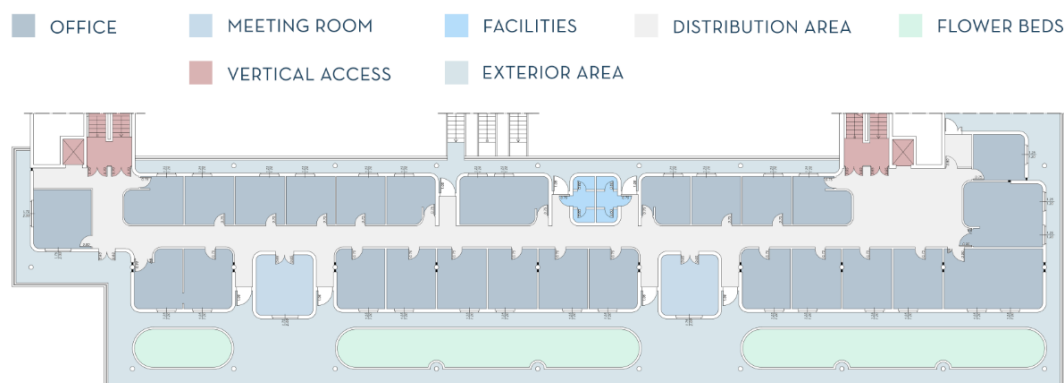


Figure 4.7: Function diagram, Floor G, La Nave, Cravino Campus. Source: [Author].

4.2.2 *Spatial criticalities for cognitive work*

The analysis of the current planimetric layout, interpreted through the parameters of neuroarchitecture, highlights significant spatial criticalities for the navigation and exploration of the architectural space (Table 4.3). The main issue affecting the central axis of floor G can be described in terms of a pronounced tunnelling effect. From an isovist analysis, an observer walking along the corridor enjoys high longitudinal visual penetration (frontal Prospect) but is subjected to the almost complete suppression of lateral visual expansion (peripheral Low Visual Openness). The lack of lateral viewpoints or transversal glimpses forces the perceptual system into a rigid, constrained perspective, inhibiting the natural unfolding of the exploratory eye scanning (R. Kaplan & Kaplan, 1989).

In addition, the rigid orthogonal regularity of doors, jambs, and wall junctions produces a high frequency of visual edges along the field of view. The combination of these characteristics, together with the narrow width of the corridor, is expected to induce sustained visuospatial processing demand, observable through parietal alpha desynchronization (Visual Processing Effort). Walking along this strongly channelled axis amplifies the individual's sense of exposure, as they are inserted into an obligatory trajectory of niches or recesses that could provide proxemic protection (Refuge), thus theoretically generating measurable levels of arousal (Berlyne, 1971; Appleton, 1975).

<i>Space</i>	VO	PC	Expected cognitive effect
<i>Centrale corridor</i>	Low	High	Visuospatial stress; sustained cognitive effort; proxemic vulnerability along the obligatory trajectory (total absence of Refuge); activation of the alerting system
<i>Cellular offices</i>	Low	Low	Short-term sense of control and proxemic Refuge; progressive sensory deprivation with prolonged exposure; reduction in sustained attention
<i>Connective zones/ atrium</i>	High	Variable	Elevated arousal potential; peripheral hypervigilance due to absent Refuge; neuroergonomic balance contingent on PC level

Table 4.3: Neuroarchitectural classification of the existing spatial typologies of floor G according to their Visual Openness (VO) and Perceived Complexity (PC) profiles and their associated expected cognitive effects based on the theoretical frameworks outlined in §2.2.

4.2.3 *User flow analysis and movement patterns*

The spatial criticalities discussed in the previous section significantly influence the behavioural mobility of occupants. Floor G's spatial usage flows demonstrate a clear trend towards a rigid, unidirectional circulation system with a limited number of possible paths determined by a central corridor (Figure 4.8).

Since there is no secondary network, all occupants must follow the same route from the primary entry node to reach their individual offices. In terms of neuroergonomics, this spatial organization does not allow for any exploratory activity or decision-making during navigation, making the occupants' movement predictable and visually directed.

The central axis of floor G creates a tunnelling effect. As they move through space, occupants experience only frontal visual penetration, lacking lateral expansion of their field of view, making it difficult to employ saccadic movements to explore the environment. This means that navigation imposes a strict forward gaze direction and,

in theory, increases visual processing requirements.

To visually represent these effects, the following diagram shows the spatial limitations to occupant movement. The flowlines emphasize a unidirectional characteristic of circulation, which illustrates how the geometry of the corridor determines a fixed trajectory, thus limiting the spatial freedom of the occupants. This constrained movement logic informed the design of the MR exploration task (Section 3.5.2), ensuring consistency between real spatial behaviour and experimental simulation.

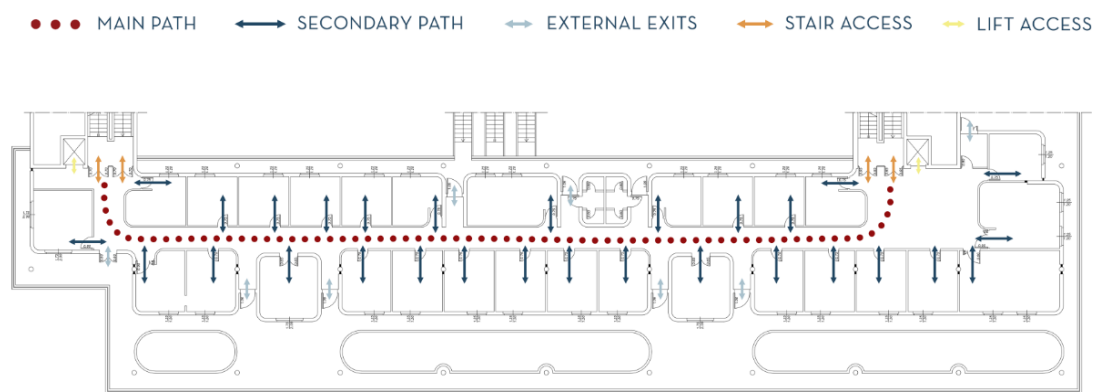


Figure 4.8: Flow diagram, Floor G, La Nave, Cravino Campus. Source: [Author].

4.3 From real space to experimental model

4.3.1 *Structural invariants and geometric constraints*

To translate the distributional criticalities observed on floor G into a valid neuroarchitectural protocol, it was necessary to selectively abstract the physical space. This phase represents the critical methodological transition from real architectural space to a controlled experimental environment.

To scientifically quantify the effect of the two independent variables under study (Visual Openness and Perceived Complexity), it was essential to fix the main architectural elements of the structure and treat them as constants in the experiment. This procedure made it possible to define the structural invariants of the model. Specifically, the original load-bearing mesh of the steel frame (pillars and main beams), the external envelope (vertical closures), and the net height of the ceiling intrados were maintained as in the real building. These elements correspond to the fixed architectural

syntax of Giancarlo De Carlo's project and represent the geometric premises and impassable physical limits for subsequent three-dimensional simulations.

From a methodological point of view, the decision to preserve these real-world constraints is motivated by the need to ensure the ecological validity of the Mixed Reality simulation. As highlighted by the literature, studying subjects in completely decontextualized virtual environments, or in spaces characterised by abstract proportions, can invalidate the applicability of the results (Banaei et al., 2017). Conversely, anchoring the simulation to the actual structural grid of "La Nave" ensures that the neurophysiological reactions recorded during the experiment can be used to formulate future retrofit guidelines applicable to this specific building.

4.3.2 Definition of the morphological bounding box for MR simulation

Once the structural invariants of the building had been defined, the last step before performing the experimental simulations was to determine the morphological bounding box. The bounding box defines the invariant spatial envelope within which all experimental manipulations occur. Considering the entire surface of floor G as a spatial matrix, the space was simplified through a digital process.

Using Rhinoceros 8 modelling software, the volume of the entire floor was stripped of all non-load-bearing architectural elements. Through this procedure, the internal plasterboard partitions, the infill walls, and all furniture were removed from the three-dimensional model.

The effect of this removal process is the generation of a pure volumetric matrix. The resulting empty space, delimited exclusively by the slabs and De Carlo's original steel grid, becomes the spatial starting point of the experiment. This bounding box represents the neutral three-dimensional canvas needed to control the Visual Openness and Perceived Complexity variables during the development of virtual scenarios. The defined bounding box and structural invariants constitute the geometric framework for the generation of the four experimental scenarios presented in Chapter 5.

5. GENERATION OF SCENARIOS AND PARAMETRIC VALIDATION

5.1 Generation of the virtual scenarios

The shift from neuroarchitectural theory to empirical experimentation required translating the concepts of visual openness and perceived complexity into three-dimensional models for exploration. To achieve maximum methodological rigor, it was decided to follow a deductive path for the modelling phase. The research was based on a theoretical and abstract analysis of spatial shapes, and only the most significant and adaptable configurations were adapted to the physical constraints of floor G of "La Nave". A reduction strategy was applied to isolate extreme conditions and maximize experimental contrast. This approach allowed us to obtain a set of virtual environments in which geometric variables could be measured mathematically, maintaining the realism necessary for a Mixed Reality experiment.

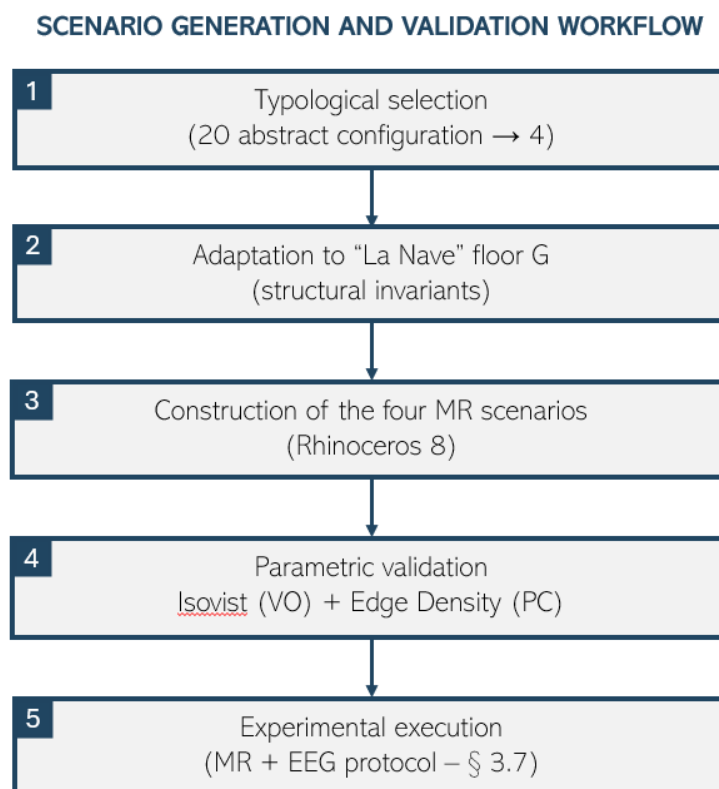


Figure 5.1: Scenario generation and validation workflow, from abstract typological selection to MR-EEG experimental execution. Source: [Author].

5.1.1 Abstract typological exploration and scenario selection

The generative process began through research organized according to 20 different spatial configurations (Figure 5.2). In this initial phase, the layouts were developed in a purely theoretical way, totally disjointed from the geometric context or structural mesh of the case study. Through this typological exploration, it was possible to map various spatial options, freely exploring the different levels of density, orthogonal disruption, and visual obstacles. The goal was to understand how topological manipulation influenced visual-spatial processing effort, the involuntary neurological effort required by the brain to decode its surroundings.

However, applying the entire set of 20 abstract abacus configurations to a neurophysiological experiment would not have been methodologically possible. Testing numerous intermediate variants would have generated data that were easily superimposable and, therefore, difficult to isolate statistically. To unequivocally demonstrate the influence of geometry on proxemic stress and attention, it was necessary to work exclusively with edge cases, eliminating all hybrid solutions.

The 20 abstract models were the subject of a strong selection with reference to two complementary needs. The first is of a scientific nature and concerns the need to select only the configurations that represent the extreme values of the two variables under consideration: Visual Openness (VO) and Perceived Complexity (PC). The second necessity of an architectural nature required that such abstract figures could be adapted to the floor G while maintaining all the proportions and structural invariants, so that they could adapt without distorting their original geometric essence.

Four fundamental paradigms of spatial configurations emerged from the screening process. These models were finally inserted inside the bounding box of “La Nave”, forming the four scenarios of the experimental matrix 2x2:

- **Scenario 1 (Baseline):** Closed and orthogonal space, with low Visual Openness (low VO) and Perceived Complexity (low PC).
- **Scenario 2:** Open and orthogonal space, which ensures high Visual Openness (high VO), together with low Perceived Complexity (low PC).
- **Scenario 3:** Closed and fragmented space, with low Visual Openness (low VO) and high Perceived Complexity (high PC).
- **Scenario 4:** Open and fragmented space, which ensures maximum exposure to

stimuli thanks to high Visual Openness (high VO) and high Perceived Complexity (high PC).

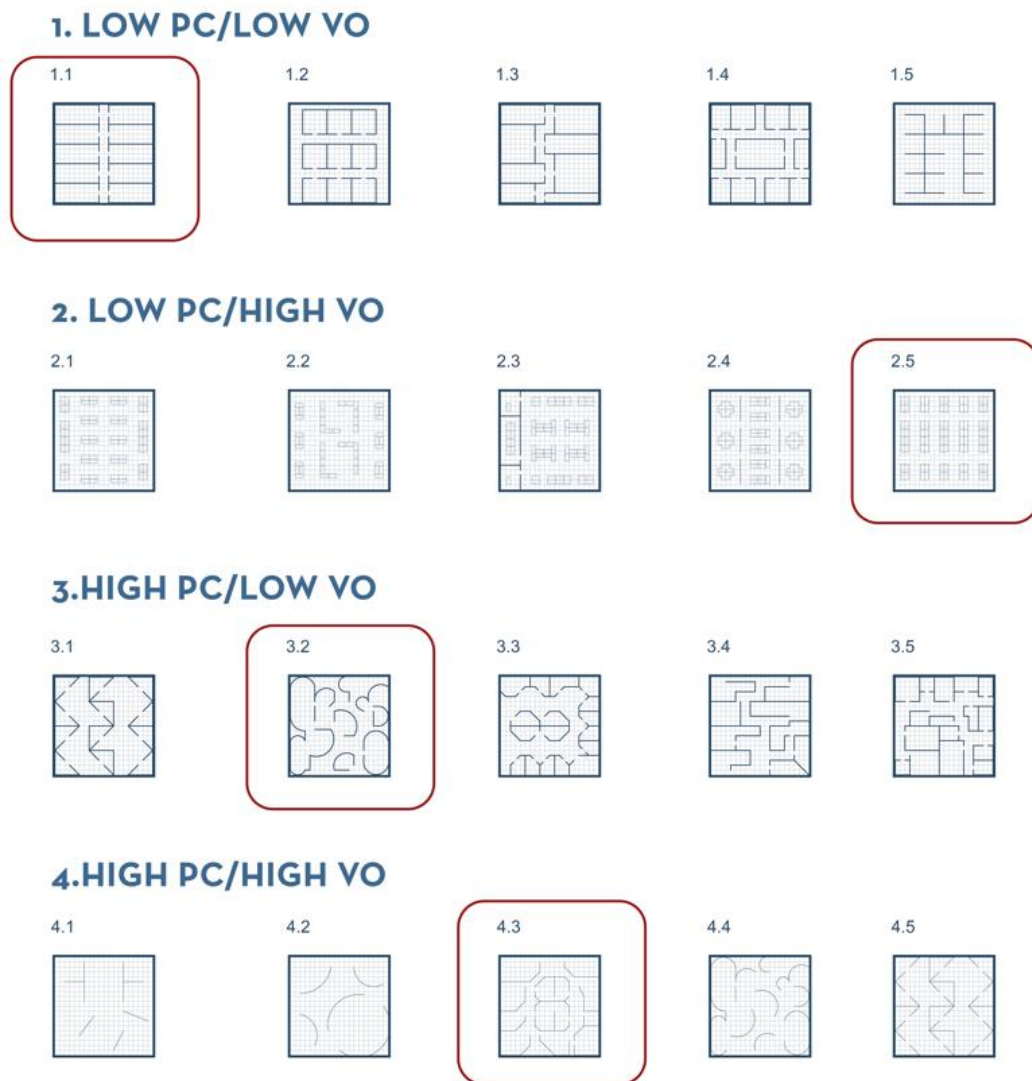


Figure 5.2: Morphological abacus of the 20 abstract spatial configurations generated for the study. The layouts are categorised into four typological quadrants based on the interaction between PC and VO. The variants highlighted in red (1.1, 2.5, 3.2, 4.3) represent the final scenarios selected for the subsequent MR-EEG experimental phase. Source: [Author].

5.1.2 *Scenario 1 (Baseline): Low VO/Low PC*

The first scenario generated corresponds to the control condition, that is the experimental baseline, for all tests in the study. The selected abstract model was inserted inside the bounding box of floor G, forming an orthogonally organized distribution space, very similar to conventional office spaces.

The goal was to minimize Visual Openness (low VO) with a simple, repetitive geometry (low PC). As a result, the scenario was composed of full-height vertical partitions that firmly delineate a long central distribution corridor and a sequence of enclosed rooms on the sides (Figures 5.3, 5.4). This morphology is characterized by the almost complete blocking of the transversal sightlines of the passing user, thus limiting visual perception exclusively to frontal perspective and producing the tunnelling effect previously discussed.

In terms of Perceived Complexity, we chose to use the right angle as the exclusive generator of the layout. There are therefore no diagonal offsets, protrusions, or unnecessary architectural details of the walls. This rigor has made it possible to minimize the number of visible edges and surfaces (edge density), thus reducing the amount of information that must be processed during movement through space.

An important aspect in the design of this scenario involved the integration of the existing structural mesh of “La Nave.” To avoid possible confusion caused by the presence of steel pillars and eliminate any visual noise, in this scenario, the partitions were arranged to incorporate the structure into its thickness along the direction of the corridor. In this way, visual interference from the backbone was neutralized, ensuring that the only responses collected from the neurophysiological data were referred to a closed, pure orthogonal space.

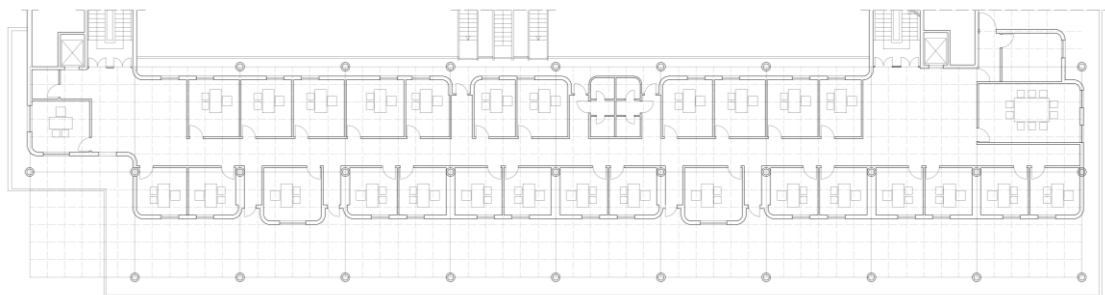


Figure 5.3: Floor plan of Scenario 1 (Baseline: Low VO/Low PC). The design features a traditional orthogonal layout with full-height partitions, creating isolated cellular offices and ensuring low perceived complexity alongside high visual occlusion. Source. [Author].

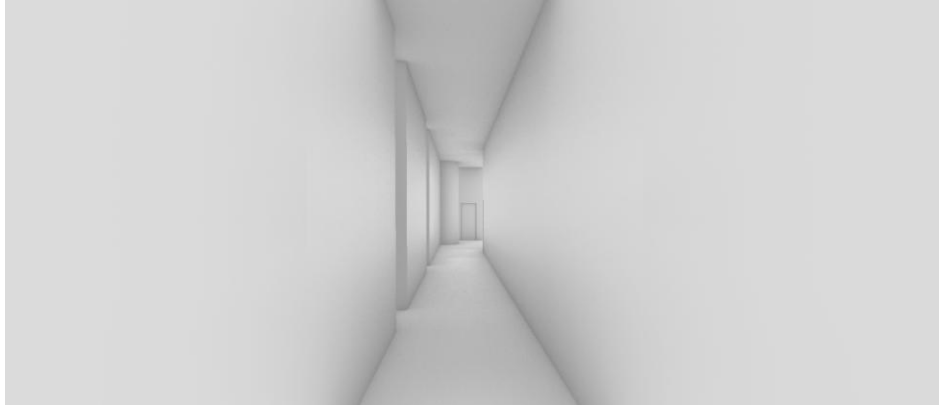


Figure 5.4: Visualization of the view seen through the Meta Quest 3 headset for Scenario 1 (Baseline: Low VO/Low PC). Source. [Author].

5.1.3 Scenario 2: High VO/Low PC

The second scenario was developed to overturn the visual experience of the previous model, trying to implement the exact opposite, namely, maximum spatial and visual permeability in a system with high geometric rigidity. In neuroarchitectural terms, this spatial arrangement aims to test the impact of a high Prospect, characteristic of open-space offices, without at the same time causing visual overload related to fragmented geometries (Low PC).

According to the planimetric analysis, the spaces are organized into a network of modular enclosures around the workstations (Figures 5.5, 5.6). To achieve the maximum effect of high visual aperture, the partitions that make up these compartments were modelled with limited height. This configuration delimits the surface area, but at the same time allows the observer's eye to master the entire scene. To this end, the observer's position was placed 1.65 meters above the ground and in such a way that his gaze could cross the divisions, filling the entire bounding box in depth and width.

Despite the open floor plan, Perceived Complexity was maintained at its lowest values. To this end, the plan was rigidly orthogonal: the compartments follow the longitudinal axis of the building in parallel, repeating themselves in the same way for several metres. There are no elements that create diagonal articulation and there is no spatial disengagement. This extreme linearity reduces the enormous visual effort required of the observer's brain to decode the environment.

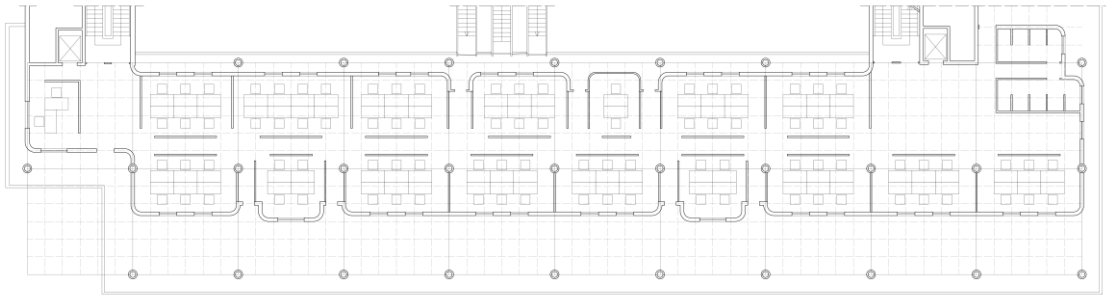


Figure 5.5: Floor plan of Scenario 2 (High VO/Low PC). The orthogonal grid is maintained, but partitions are lowered to 1.20 meters. This configuration establishes a standard open-plan environment, maximizing visual openness and minimizing geometric complexity. Source. [Author].

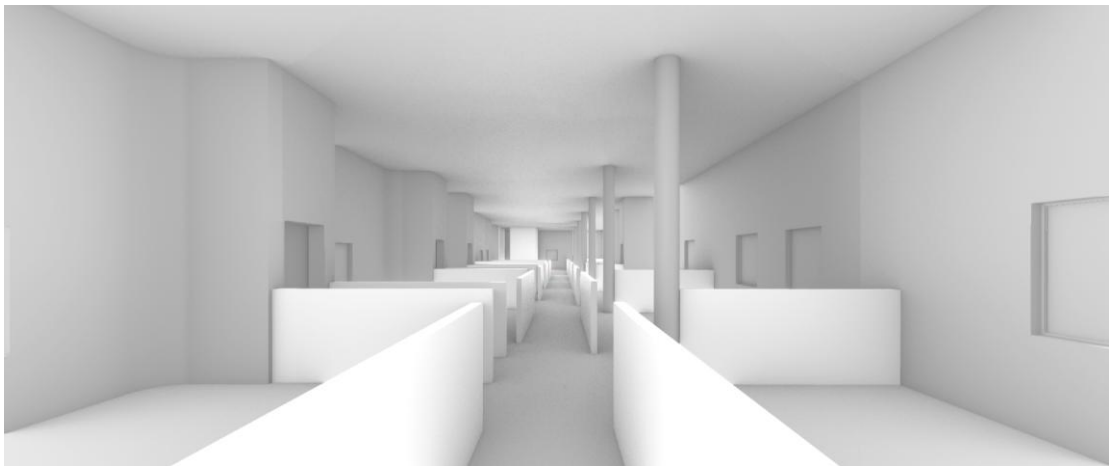


Figure 5.6: Visualization of the view seen through the Meta Quest 3 headset for Scenario 2 (High VO/Low PC). Source. [Author].

The main methodological challenge of this configuration was the management of the supporting pillars of “La Nave”. The absence of full-height walls necessarily exposes the structural steel mesh. The pillars were left in their original exposed position. It has been considered scientifically correct not to hide them, although their emergence introduces a visual frequency quota. Indeed, their presence guarantees the ecological validity of the simulation and demonstrates how an open layout must always mediate with pre-existing structural structures. The impact of this decision was mitigated by the linearity of the low parts, ensuring that the scenario remained solidly in the Low PC quadrant.

5.1.4 Scenario 3: Low VO/High PC

The third scenario was designed to isolate and quantify the effect of geometric fragmentation (High PC) while keeping the user under visual closure conditions (Low VO). While the baseline (Scenario 1) involved hypo-stimulating a straight, orthogonal corridor, the third scenario pushes the boundaries of visual-spatial processing to the extreme, narrowing the distributional path into a complex configuration with multiple unexpected turns (Figures 5.7, 5.8).

As indicated by the planimetric restitution, the orthogonal nature of the previous models was deliberately demolished. The internal partitions no longer follow straight axes or modular sequences, but have been reconstructed using organic geometries, curved lines, and concave/convex profiles. Such an irregular design of perimeter walls breaks conventional spatial references, forcing the distribution corridor to meander asymmetrically and continuously. Therefore, the number of surfaces, overlaps, and optical breaks that the user will encounter across their field of view will increase exponentially, saturating the Edge Density parameter.

The high levels of complexity at the planar organization level, in the vertical section, maintained absolute rigidity. To ensure the maintenance of a low Prospect (Low VO), all irregular and curved walls framing the work areas have been extruded to their maximum height, completely blocking lateral visibility by the observer.

The combination of high walls and organic planar organization leads to an extremely peculiar perceptual condition: a labyrinthine tunnelling effect. Unlike Scenario 1, where the visual passage allowed a longitudinal path, in Scenario 3 the curvilinear trend of the walls constantly interrupts the frontal perspective, forcing the user to navigate uncertainly, lacking broad, reassuring views and the maximum attention required to decode the boundaries of the environment.

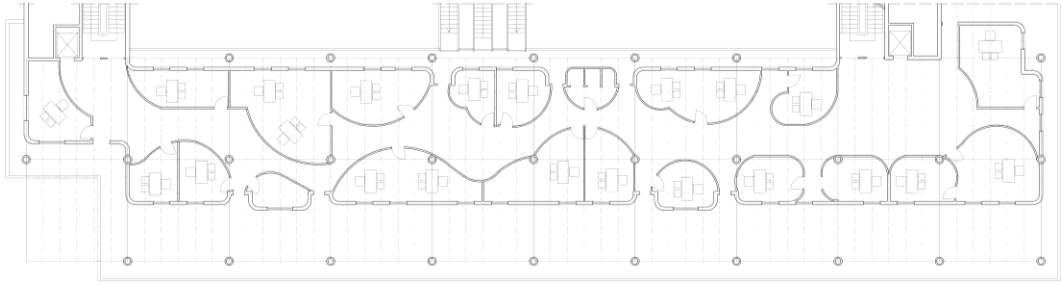


Figure 5.7: Floor plan of Scenario 3 (Low VO/High PC). A highly fragmented, labyrinthine configuration characterized by organic, non-orthogonal walls extending to full height. This layout severely restricts visual depth while drastically increasing geometric articulation. Source. [Author].

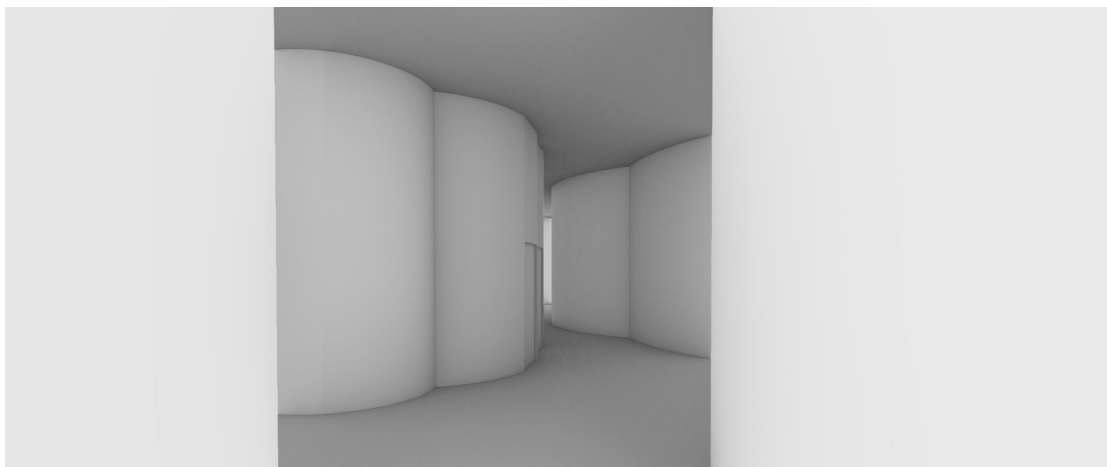


Figure 5.8: Visualization of the view seen through the Meta Quest 3 headset for Scenario 3 (Low VO/High PC). Source. [Author].

5.1.5 Scenario 4: High VO/High PC

The fourth scenario represents the extreme experimental condition, designed to simultaneously saturate the two neuroarchitectural poles of space, through maximum spatial permeability (High VO) combined with high shape complexity (High PC). While scenario 3 was characterized by the investigation of organic and curved shapes in an internal space, in this model, the interest focuses on the possibility of exploring the maximum permeability of the space in an environment dominated by irregular edges and angles (Figures 5.9, 5.10).

Analysis of its floor plan shows that, unlike the first two scenarios, the distribution path and workstation envelopes are constructed using irregular and zigzag lines, broken angles, sharp corners, and sudden changes of direction.

As a result, parallelism is severely disrupted in favour of many vertices and intersections of the walls. Visually, the morphology of this scenario ensures saturation

5.GENERATION OF SCENARIOS AND PARAMETRIC VALIDATION

of the Edge Density parameter, thus requiring constant brain processing effort to decode a complex and fragmented geometry.

The key change in this scenario concerns vertical sections. By analogy with the logic of the second scenario, in which all the walls were eliminated, here all the jagged partitions were radically reduced to a standard height of only 1.20 meters. Therefore, it is possible to consider the volume fully revealed, walking in an irregular and angular path, so that each user can see clearly beyond all barriers. The gaze, placed at 1.65 meters, allows scanning the area and visually clearing all barriers, and integrates the entire bounding box with all emerging structural pillars into its field of view.

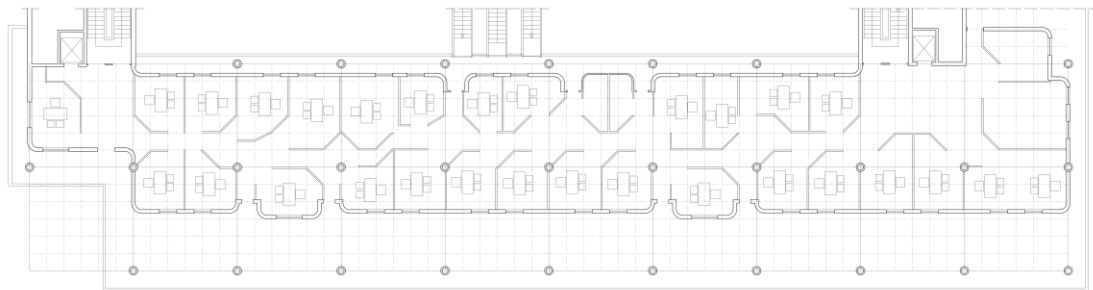


Figure 5.9: Floor plan of Scenario 4 (High VO/High PC). The irregular, zig-zag geometric footprint of scenario 3 is maintained, but the partitions are uniformly reduced to 1.20 meters. This layout juxtaposes high structural complexity with extensive spatial visibility. Source: [Author].

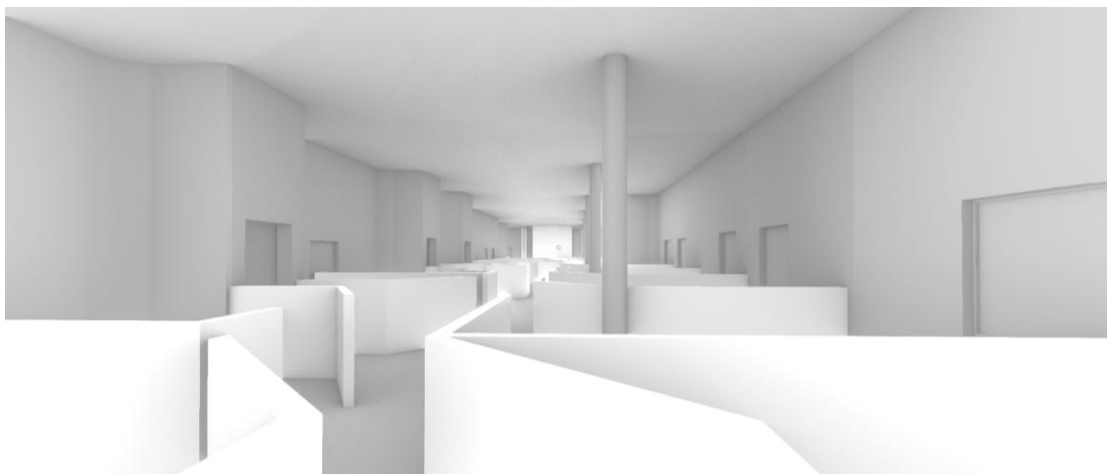


Figure 5.10: Visualization of the view seen through the Meta Quest 3 headset for Scenario 4 (High VO/High PC). Source: [Author].

At the neuroarchitectural level, scenario 4 triggers intentional cognitive overload in the brain's attentional system. The user is faced with a condition of proxemic hyper exposure (lack of shelter due to low partitions) with the neurological need to simultaneously process many angular obstacles that are misaligned in depth. The visual superposition of the structural mesh of the pillars with the geometric chaos of the underlying walls completes the picture of an architectural stimulation pushed to the limit of visual-spatial tolerance.

5.2 Parametric validation of the spatial variables

Parametric analysis aims to objectively demonstrate the compatibility between the theoretical intentions underlying the 2x2 neuroarchitectural model and the actual spatial configuration generated in a digital environment. To demonstrate the independence and saturation of the two variables involved, VO and PC, two separate quantification methods were used: syntactic-spatial analysis using Isovist and image analysis using Edge Density. This phase ensures that the design scenarios effectively represent the intended experimental conditions.

5.2.1 Validating VO using Isovist analysis

The variable VO was quantified using the isovist technique, a Space Syntax methodology that calculates the amount of space visible from any point within a closed environment. For ecological validity, the two-dimensional cutting plane used to calculate the algorithm in Rhinoceros was set to an altitude of +1.65 meters above the floor level, corresponding to the standard eye height of the observer in the standing position.

The parametric extraction of the data was conducted through the isovist.org software, an advanced spatial analysis application developed for the syntactic decoding of architectural environments.

According to the analysis, the values for the parameters of Area, directly correlated to the concept of Prospect, that is the available visual amplitude, and Occlusivity, that is the length of the visual margins interrupted by obstacles, correlated to the level of uncertainty and potential arousal of the environment, were calculated.

The calculation was performed comparatively for the conditions of "Low VO" (scenarios 1 and 3) and "High VO" (scenarios 2 and 4).

- **Low VO** (scenarios 1 and 3): In scenarios where all partitions are full height, the mean values of the isovist area (Prospect) reach 1.99 m², delineating extremely small and fractionated fields of view. The proximity of the occlusive barriers at the gaze level saturates the environment with immediate obstacles, mathematically confirming the condition of physical closure and the high level of visual restraint (Refuge).
- **High VO** (scenarios 2 e 4): In scenarios where partitions are lowered to 1.20 meters, the cutting plane at +1.65 m does not intersect the low dividers. The net increase in visibility area of +310% shows that the field of view opens. The observer benefits from an extended Prospect that covers large projections of the floor plan, extending to the physical limits of the bounding box.

Comparing scenario 2 and scenario 4 yields a methodologically crucial fact. Both scenarios return identical isovist values (area, perimeter, occlusivity, etc.). From this perspective, there is no reason to consider it an anomaly; instead, it provides evidence that the VO variable was successfully manipulated separately from the PC. If the horizon of the human eye is placed at a height of +1.65 m, the space becomes equally open, allowing the observer to see an equal extent and perspective regardless of the geometric complexity present at a height of 1.20 m. Orthogonal and regular, represented by scenario 2, versus irregular and fragmented, represented by scenario 4.

The mathematical identity of the 2D isovist data confirms that the spatial aperture has been successfully isolated. Consequently, the next step will be to measure how cognitive complexity, calculated on three-dimensional views, increases below the visual threshold.

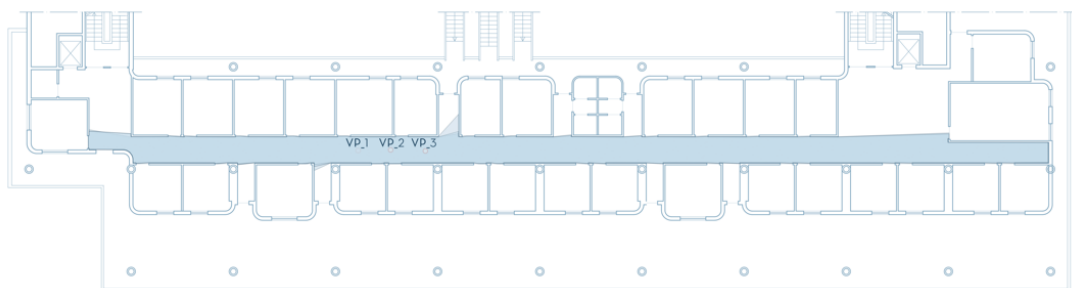


Figure 5.11: Isovist analysis of scenario 1. Source: [Author].

5.GENERATION OF SCENARIOS AND PARAMETRIC VALIDATION

Ref	x	y	Sweep	Heading	Range Far	Range Near	Drift	Area	Occlusivity	Vista	Perimeter	Compactness	Overt Control	Covert Control	CoVisibility	Choice	Mean Visual Depth
1	38,560	18,464	360,000	180,000	86,000	0,000	1,965	1,998	0,316	6,205	17,920	0,078	17,617	1,124	2,108	0,600	2,475
2	40,932	18,523	360,000	180,000	86,000	0,000	1,682	1,991	0,316	5,905	17,865	0,078	16,813	1,134	2,116	0,600	2,475
3	43,066	18,464	360,000	180,000	86,000	0,000	1,417	1,997	0,316	5,635	17,947	0,078	17,652	1,126	2,109	0,600	2,475
Mean values								1,995			17,911						2,475

Table 5.1: Isovist analysis of scenario 1. Parameters confirm minimal visual openness and high spatial occlusion.

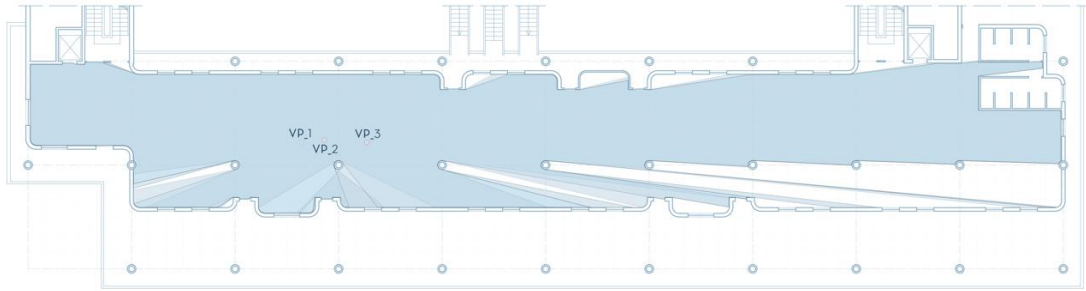


Figure 5.12: Isovist analysis of scenarios 2 and 4. Source: [Author]

ref	x	y	Sweep	Heading	Range Far	Range Near	Drift	Area	Occlusivity	Vista	Perimeter	Compactness	Overt Control	Covert Control	CoVisibility	Choice	Mean Visual Depth
1	30,848	22,421	360,000	180,000	86,000	0,000	2,134	8,106	0,622	6,800	34,129	0,087	20,441	0,981	7,187	0,383	1,252
2	33,602	22,421	360,000	180,000	86,000	0,000	1,771	8,217	0,573	6,453	31,845	0,101	20,716	0,964	7,172	0,374	1,234
3	36,306	22,421	360,000	180,000	86,000	0,000	1,471	8,263	0,650	6,112	36,565	0,078	21,083	0,940	7,159	0,383	1,224
Mean values								8,195			34,213						1,237

Table 5.2: Isovist analysis of scenarios 2 and 4. Metrics reflect total visual exposure and the absolute absence of protective proxemic boundaries.

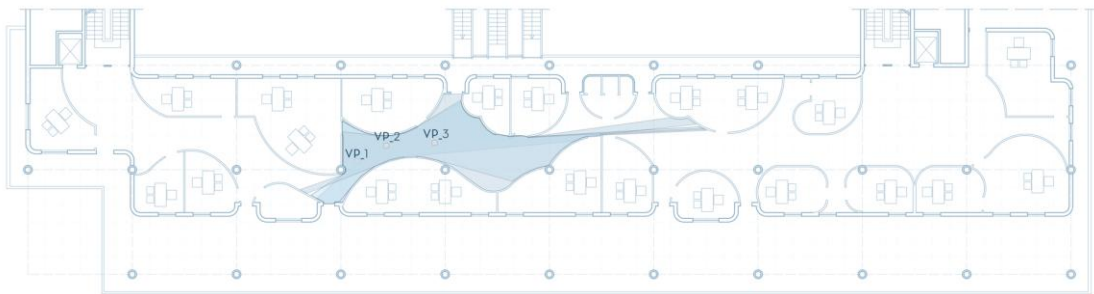


Figure 5.13: Isovist analysis of scenario 3. Source: [Author]

ref	x	y	Sweep	Heading	Range Far	Range Near	Drift	Area	Occlusivity	Vista	Perimeter	Compactness	Overt Control	Covert Control	CoVisibility	Choice	Mean Visual Depth
1	34,013	13,646	360,000	180,000	86,000	0,000	0,518	0,470	0,611	2,770	7,330	0,110	32,478	1,626	0,646	0,510	2,769
2	36,325	14,831	360,000	180,000	86,000	0,000	0,539	0,775	0,562	2,753	8,184	0,145	52,854	0,986	0,707	0,645	2,182
3	39,645	14,950	360,000	180,000	86,000	0,000	0,260	0,779	0,502	2,322	8,244	0,144	50,302	1,007	0,717	0,639	2,406
Mean values								0,674			7,919						2,452

Table 5.3: Isovist analysis of scenario 3. Values indicate excessive spatial fragmentation and continuous interruption of the visual field.

5.2.2 *Validation of PC using Edge Density*

Although the isovist assessment provided an objective assessment of VO within the horizontal plane, PC assessment requires a different indicator capable of assessing the density of visual stimuli in a three-dimensional environment. Therefore, the chosen measurement was Edge Density (ED), which represents the ratio between the pixels corresponding to the edges (corners, intersections, geometric contrast variations) and all pixels in an image, expressed as a percentage. In the neuroarchitectural literature, it has been shown that higher values of this parameter are directly correlated with a greater load of visual information and therefore with greater perceived spatial chaos (Machado et al., 2015; Stamps, 2002).

For each of the four conditions, three internal perspectives were adopted to create an objective representation of a subjective visual experience, at the eye level. The images rendered in constant size (1920x1080 pixels) were analyzed using a custom Python script. Specifically, the Canny Edge Detector algorithm was used to detect edges in the images automatically. This operator allows you to isolate pixels corresponding to actual edges, intersections, and contrast variations and calculate the percentage of those pixels compared to a total of 2,073,600 for each image.

Data analysis highlights the objective changes in visual density created by altering the spatial configuration, thus confirming the saturation of the PC variable:

- **Closed-space condition (low VO):** Comparison of scenarios with high partitions shows that switching from the orthogonal configuration (scenario 1) to the curvilinear configuration (scenario 3) results in a tangible increase in ED. The average ED value in Scenario 1 is 0.21%. By adding contoured surfaces and asymmetric envelopes in Scenario 3, the average value is increased to 0.31%. This absolute increase of +0.10 indicates the fact that organic geometry, despite being confined to a visually occluded space, offers a greater amount of visual information to process.
- **Open space condition (high VO):** The same principle applies to configurations with lower partitions. While Scenario 2 (orthogonal) shows an average ED value of 0.88%, in Scenario 4 (high PC), with its jagged geometry of the low partitions, rich in zigzag corners and recesses, causes the ED to reach an average peak of 0.95%. The absolute increase of +0.07% demonstrates that the irregularity of the spatial arrangement affects the visual load despite the absence of occlusive elements.

The most obvious aspect of the data obtained is the drastic percentage increase in ED that occurs when crossing the two variables. The transition from the visual occlusion scenario (with mean ED values between 0.21% and 0.31%) to the open condition (values approximating 1%) produces a substantial increase in ED. This divergence mathematically confirms the combined effect of VO and PC; the lowering of the partitions reveals the structural mesh and surrounding enclosures at depth. The perspective overlap of these elements multiplies the number of visible edges, significantly increasing the measurable visual complexity of the scene.

VP	Pixel tot. (1920x1080)	Edge pixels	Edge density
1	2.073.600	3.698	0,18
2	2.073.600	4.216	0,20
3	2.073.600	5.134	0,25
			0,210

Table 5.4: Edge Density analysis of Scenario 1. Minimum values (mean ED = 0.21%) confirm the condition of low structural complexity.

VP	Pixel tot. (1920x1080)	Edge pixels	Edge density
1	2.073.600	17.342	0,84
2	2.073.600	19.528	0,94
3	2.073.600	18.128	0,87
			0,883

Table 5.5: Edge Density analysis of Scenario 2. The mean value of 0.88% mathematically confirms the low Perceived Complexity condition in an open layout.

VP	Pixel tot. (1920x1080)	Edge pixels	Edge density
1	2.073.600	3.698	0,22
2	2.073.600	4.216	0,27
3	2.073.600	5.134	0,44
			0,310

Table 5.6: Edge Density analysis of Scenario 3. The mean value of 0.31% confirms the condition of high structural complexity within a closed layout.

VP	Pixel tot. (1920x1080)	Edge pixels	Edge density
1	2.073.600	19.328	0,93
2	2.073.600	20.222	0,98
3	2.073.600	19.570	0,94
			0,950

Table 5.7: Edge Density analysis of Scenario 4. The mean value of 0.95% mathematically validates the configuration of high PC in an open layout.

5.3 Experimental execution and methodological limitations

5.3.1 Laboratory setup and hardware coexistence

The experimental execution follows the protocol defined in Chapter 3. For the testing phase, it became essential to perform a 1:1 scale superposition of the models generated by Rhinoceros onto the real floor G environment of "La Nave". While the colour passthrough technology of the Meta Quest 3 allowed scenarios to be anchored to the real environment, practical implementation revealed significant ergonomic and technical challenges.

The main limitation encountered during the experiment setup concerned the physical possibility of wearing two units mounted on the participants' heads simultaneously. The Mixed Reality headset (Meta Quest 3) and the neurophysiological helmet (Emotiv EPOC X) compete for the same anatomical area.

Specifically, the headset strap tended to press or move the front and temporal EEG electrodes.

Furthermore, a severe limitation associated with the issue of signal transmission emerged: the volume of the participants' scalp tissue. The hair acts as a natural physical insulator and significantly reduces the impedance of moistened felt pads, affecting the sensitivity of the delicate parietal and occipital sensors (required for Alpha Desynchronization). Achieving the minimum skin conductivity threshold required substantial time and effort to precisely adjust the hair, ensuring direct contact between the scalp and the electrodes.

5.3.2 Execution of motor sessions and EEG artefact management

The experiment was conducted by requiring the 20 participants to perform a standardized motor task (walking 5 meters forward and 5 meters backward) in four different environmental contexts. The use of the MoBI paradigm ensured a high degree of ecological validity, enabling the recording of neural responses during active exploration, overcoming the limitations of classical EEG experiments conducted in a static sitting position.

However, from a purely technical point of view, body movement and head movement during locomotion have inevitably introduced a rather high amount of noise into the electroencephalographic signal. The movement itself, combined with the need to support and balance the weight of the two head-mounted devices, created artifacts caused by muscle contraction in the neck and jaw. Second, eye movements caused the appearance of electrooculographic (EOG) artifacts.

To address these critical issues inherent in dynamic measurement, the protocol set subjects to an extremely slow and controlled walking pace.

5.3.3 Spatial safety and ecological validity

Another important issue raised in the context of the tests concerns the participants' sense of safety and balance while walking. Navigating occlusive or fragmented virtual environments introduces the risk of simulation-induced cybersickness and postural disorientation.

It is precisely in this regard that Mixed Reality can be considered a turning point in methodological terms. In fact, thanks to passthrough technology that provides users

with a view of their bodies and the real floor beneath the virtual walls created by the algorithms, it has become possible to almost completely prevent the occurrence of dizziness.

This condition ensured that the alterations in cognitive load and proxemic stress recorded by the EEG sensors were attributable solely to the geometry of the manipulated architectural space (VO and PC) and not affected by the fear of physical collisions or by malaise induced by the projection system.

5.4 Synthesis of experimental setup

At this point, the experimental procedure is complete and validated, providing a solid methodological basis for the subsequent analysis of the collected data. Thus, the experimental generation process described above successfully converted the initial abstract theory into four measurable spatial conditions based on La Nave's floor G geometry.

The experimental matrix can be briefly summarized as follows:

- **Scenario 1 (Baseline / Low VO - Low PC):** A conventional orthogonal layout with full-height partitions.
- **Scenario 2 (High VO - Low PC):** An orthogonal open-space configuration with 1.20-meter partitions, which maximizes visual depth while maintaining morphological rigidity.
- **Scenario 3 (Low VO - High PC):** A highly fragmented and labyrinthine environment with full-height organic partitions, which severely limit visual openness.
- **Scenario 4 (High VO - High PC):** A spatially permeable but morphologically complicated scenario, with low partitions and a very irregular zigzag geometry.

Ultimately, parametric validation confirmed that both independent variables were adequately isolated and successfully saturated. The results of the Isovist analysis demonstrated that the 2D visual aperture factor was correctly adjusted in all scenarios, regardless of geometric complexity. The calculation of Edge Density on 3D perceptual fields demonstrated how perceptual complexity was progressively increased from the minimum digits of Scenario 1 (0.21%) up to the maximum values of Scenario 4 (0.95%). Finally, running the experiment in Mixed Reality successfully addressed the

inherent challenges of MoBI, ensuring the ecological validity and physical safety of participants during navigation.

After being validated and verified, the experimental scenarios become ideal input conditions for further examination of psychometric assessments and cortical EEG activations, which are analysed and triangulated in the next chapter.

6. DATA ANALYSIS AND NEUROERGONOMIC RESULTS

6.1 Demographics and data treatment

This chapter presents the results of the experimental protocol, structured in three levels: subjective perception, objective neurophysiological response, and their integration. The experiment performed on floor G of “La Nave” produced a composite dataset obtained from active space exploration by 20 adult volunteer participants. In line with the inclusion criteria developed through the methodology, all subjects presented a normal or corrected-to-normal vision, an essential requirement to ensure the reliability of the visuospatial perception of VO and PC parameters.

The protocol, which involved everyone sequentially exploring all four scenarios, generated 80 valid experimental sessions (20 participants multiplied by 4 environments). Methodologically, this repeated-measures (within-subjects) design approach is a strength of the research: by allowing individuals to serve as their own controls, the specific effect of architectural variables on the neurophysiological response was isolated, neutralizing the biological and personality differences inherent in the participants.

The collected data are divided into two parallel streams, which will be analysed separately before being triangulated in the final phase of the chapter:

1. **Psychometric data (subjective):** collected using the space exploration questionnaire administered immediately after each motor task. The responses, provided on a 7-point Likert scale, were tabulated to generate descriptive statistics (means and standard deviations) that quantify users' subjective experience across the four quadrants of the experimental matrix.
2. **Neurophysiological data (objective):** Continuously recorded during walking using the Emotiv EPOC X 14-channel EEG headset. Since the research aims to evaluate the cognitive impact of architecture under ecological and non-clinical conditions, the analysis focused on qualitative observations of raw time-domain traces, namely the electrical activity of the brain recorded during the task. To test the hypotheses developed in the research, the observations focused on three specific

indicators (biomarkers):

- **Cognitive load and concentration (Frontal Theta):** detected by sensors placed on the forehead (AF3, AF4, F3, F4, F7, F8). An increase in the intensity of this wave means that the subject's brain makes a significant executive effort to decode the spatial complexity or confusion of the architectural environment.
- **Visuospatial stress (Parieto-Occipital Alpha):** detected by sensors positioned in the parietal (P7, P8) and occipital (O1, O2) regions. When the user has difficulty orienting himself or has no clear spatial references, the oscillation activity of the Alpha band in this region undergoes a drastic drop in intensity (desynchronization phenomenon), while the occipital area (O1, O2) simultaneously records the level of activation of the visual system.

6.2 Psychometric assessment

To measure the conscious impact of architectural variables (VO and PC) on user experience, subjective data were collected using a structured questionnaire called the Spatial Exploration Questionnaire. As discussed in Chapter 3, this questionnaire includes parameters established in the field of psychology and neuroergonomics but adapted for the assessment of MR space. The questionnaire consists of 11 questions (Q1-Q11), rated on a 7-point Likert scale, and is divided into four main domains: ecological validity of the simulation (spatial presence), topological perception of the architecture (environmental assessment), perceived mental effort (cognitive load and stress), and functional application of the layout (behavioural intent).

Table 6.1 presents the exact structure of the questionnaire administered to participants at the end of their exploration of each spatial quadrant. In the following sections, numerical data for these four macro areas will be analysed in the four experimental scenarios.

6.DATA ANALYSIS AND NEUROERGONOMIC RESULTS

MACRO-AREA	CODE	ITEM TEXT
1. Spatial Presence	Q1	<u>Sense of being there:</u> I had a sense of “being there” in the virtual workspace, rather than just observing images.
	Q2	<u>Spatial realism:</u> The architectural layout of the space seemed realistic and consistent with a physical office environment.
	Q3	<u>Isolation:</u> During the exploration, I lost awareness of my real physical surroundings.
2. Environmental assessment (Kaplan & Kaplan)	Q4	<u>Complexity:</u> The environment contained a high amount of distinct architectural and visual elements.
	Q5	<u>Coherence:</u> The architectural elements and partitions within the office appeared to be arranged in a logical and structured manner.
	Q6	<u>Legibility (Wayfinding):</u> If I had to move freely within this space to locate a specific desk, it would be easy to orient myself and figure out where to go.
	Q7	<u>Mystery:</u> The physical arrangement of the space made me want to explore further to see what was behind the walls or partitions.
3. Cognitive load and stress (NASA-TLX)	Q8	<u>Mental demand:</u> How much mental and perceptual activity was required to understand and navigate the layout of this space?
	Q9	<u>Effort:</u> How hard did you have to work mentally to maintain your focus on the environment without getting distracted or fatigued?

	Q10	<u><i>Frustration:</i></u> How confused, irritated, or disoriented did you feel while exploring this architectural scenario?
4. Behavioural intent	Q11	<u><i>Workplace feasibility:</i></u> If this were a real physical office, I would consider this specific architectural layout suitable for performing my daily work productively and comfortably.

Table 6.1: Structure and items of the spatial exploration questionnaire.

6.2.1 *Spatial presence and ecological validity*

The analysis of psychometric data begins with the ecological validation of the experimental procedure. To consider reliable and transferable neurophysiological parameters in architectural design, participants must perceive the MR simulation as a credible spatial environment in which to move. The results of the spatial presence measurement (Q1, Q2, Q3) showed that the experiment was successful, with mean values consistently above the neutrality threshold ($M = 4$) of the Likert scale (Figure 6.1).

As regards the first indicator (Q1 - Sense of being there), the average evaluation always exceeds the positivity threshold in all scenarios. For the Baseline scenario (Scenario 1), it stands at a value of 5.55, undergoing a slight decrease in scenario 3 (5.30) and reaching the peak of 6.00 in scenario 4 (High VO / High PC). The latter data indicate that the visual amplitude generated by low partitions maximizes the perception of being physically lowered into space.

Architectural realism (Q2 - Spatial realism) reflects a mirror dynamic. The two orthogonal scenarios, relating to conventional office types, demonstrate an equal perception of realism ($M = 5.10$), regardless of whether they represent closed offices (scenario 1) or open-space layouts (scenario 2). The minimum rating is provided by scenario 3 ($M = 4.40$). Methodologically speaking, this result can be explained because the application of curved, organic walls creates distance from a traditional office environment. However, even then, the rating remains above the neutral level of the scale, preventing any potential violation of the suspension of disbelief.

Finally, the parameter of detachment from physical reality (Q3 - Physical isolation) has the widest variations. As highlighted by the Standard Deviance (SD) bars, participants' subjectivity plays a greater role in this parameter. The sense of isolation progressively increases from the Baseline ($M = 4.55$, $SD = 2.04$) until reaching a peak in scenario 3 ($M = 5.10$, $SD = 1.80$). The combination of the absence of visual depth (low VO) and the organicity of the wall joint caused a pronounced tunnelling effect, which detached participants from the underlying physical reality, compared to scenario 4 ($M = 4.35$, $SD = 1.78$).

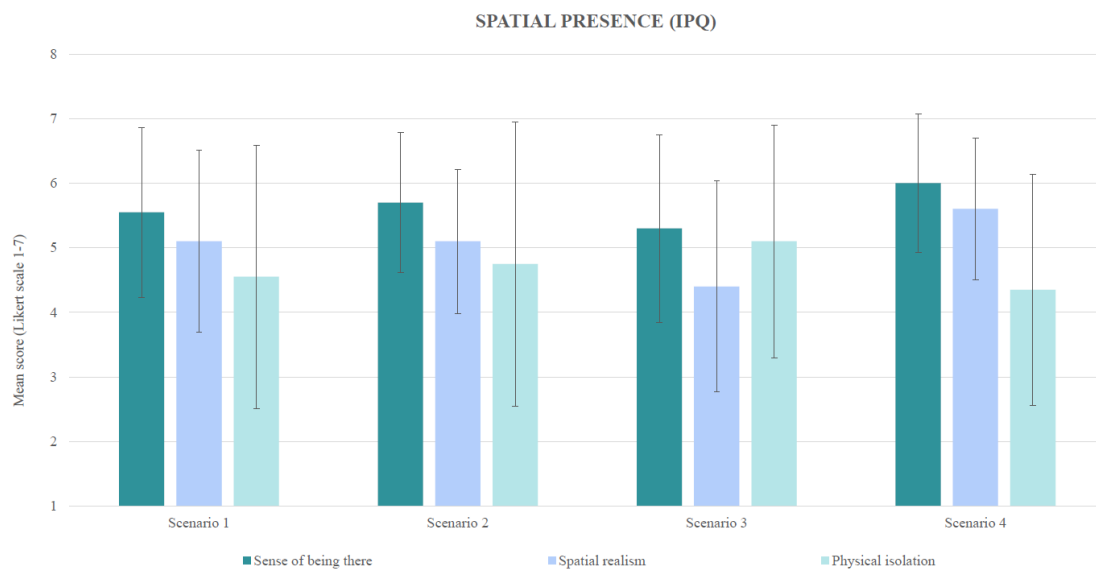


Figure 6.1: Bar heights represent the mean scores ($N=20$). Error bars indicate ± 1 Standard Deviation, illustrating response variance. Source: [Author].

6.2.2 Environmental assessment

Regarding the second axis of exploration, which investigates cognitive reaction to architecture, four of the environmental variables used in the Kaplan and Kaplan framework were considered. The histogram (Figure 6.2) shows that stimuli were received in highly differentiated ways, demonstrating the direct impact of architectural forms on user perception.

Through the variable visual complexity (Q4), a certain distinction can be observed between cell spaces and more spacious organic environments. Scenario 1 appears to have been perceived as the least complex ($M = 2.95$). This effect is due to the monotonous nature of closed spaces, which ensures rapid visual saturation of the user. In contrast, orthogonal open spaces (scenario 2; $M = 5.20$) and more irrational

variations (scenario 4, $M = 5.60$) represent extremely complex and challenging contexts due to the numerous furniture elements and interceptable partitions present in a single field of view.

In terms of the spatial coherence variable (Q5) and legibility as a wayfinding tool (Q6), a notable congruence can be noted. Specifically, scenarios 1, 2, and 4 demonstrate high levels of consistency (between 5.20 and 5.90), which were interpreted by participants as highly structured and understandable spatial patterns. Conversely, a significant reduction in these features was observed only in scenario 3, characterized by the presence of closed and curved surfaces that made it less geometrically ordered (consistency: $M = 4.10$) and completely incomprehensible to traverse (readability: $M = 3.30$) due to the lack of distant visual cues.

As for the mystery indicator (Q7), which describes the amount of new potential information contained in the environment, the results do not entirely match expectations. While scenario 3 represents the highest degree of visual occlusion, its mystery level ($M = 5.00$) does not exceed that of the other quadrants. Surprisingly, the maximum peak is recorded in scenario 1 ($M = 5.95$, $SD = 1.27$). The clear visual segmentation performed by the continuous walls of small offices evidently stimulated in the participants a strong exploratory desire to discover what lay beyond the primary physical dividers, confirming that total and close occlusion generates greater spatial curiosity than continuous permeability.

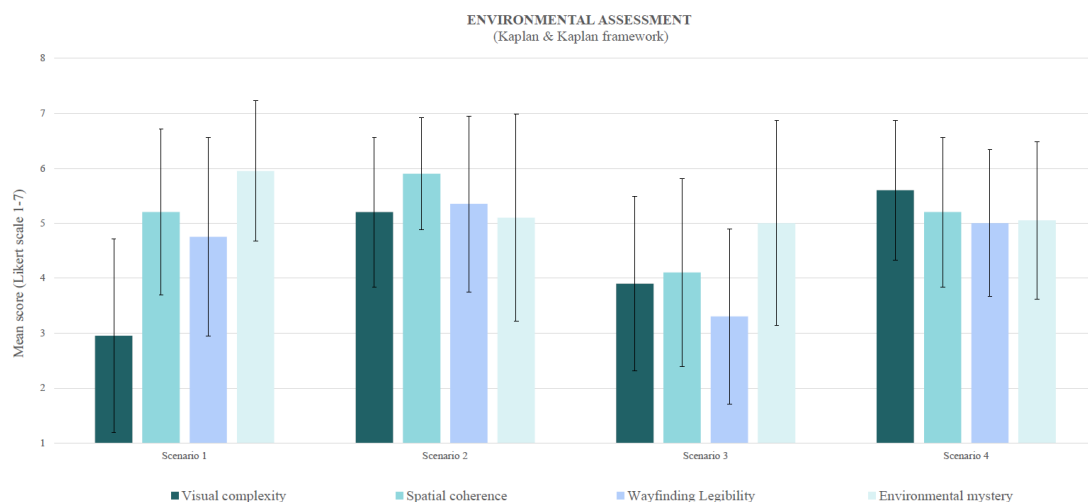


Figure 6.2: Mean score for the environmental assessment (Kaplan & Kaplan framework). Error bars indicate ± 1 Standard Deviation. Source: [Author].

6.2.3 *Cognitive load and stress*

The third macro-area is dedicated to the cognitive load of space exploration with the help of three indicators extracted from the NASA-TLX (Task Load Index). As explained in the histogram (Figure 6.3), the raw data were analytically inverted during post-processing (reverse scored): a higher value on the Likert scale represents a positive experience, less effort and greater psychological comfort.

The comparison of the data highlights a picture in partial discontinuity with the expectations relating to geometric regularity. The two simplest scenarios, characterized by a strict orthogonal grid (scenarios 1 and 2), reported means in the minor indicators for all three metrics (between 2.50 and 3.05). This finding suggests that the rigid sequence of corridors in highly regular spaces (typical of traditional offices) forced subjects to face greater difficulty in terms of cognitive load and level of frustration when generating the mental map of the environment.

The most interesting situation can be observed in the two scenarios of complex and irregular spatial configurations. Although the active MR-EEG examination process was challenging and kept all scores below the theoretical neutral threshold (4.0), a clear relative mitigation pattern was observed in the organic layouts. Scenario 3, although the one with the highest degree of visual occlusion, showed a relative improvement in terms of mental ease ($M = 3.70$) and lack of frustration ($M = 3.35$) compared to the orthogonal standard. Similar trends were observed in scenario 4, which achieved the best relative value in minimum cognitive effort ($M = 3.45$). The conclusion of this observation suggests a fundamental neuroergonomic principle: although orienting oneself in new virtual spaces can be mentally challenging, morphological fluency reduces perceived mental effort. In contrast to repetitive business spaces composed of a grid structure, organic geometries serve as a relaxing visual experience that helps cushion the overall cognitive load.

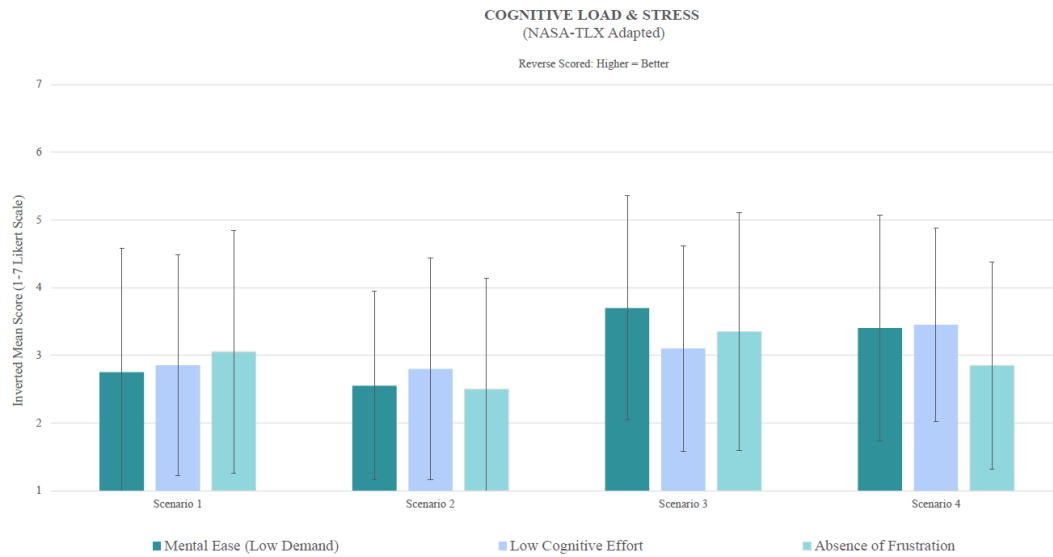


Figure 6.3: Mean score for cognitive load and stress (adapted NASA-TLX). Error bars indicate ± 1 Standard Deviation. Source: [Author].

6.2.4 Behavioural intent and workplace feasibility

The final dimension of the investigation involved transferring the evaluation from cognitive to pragmatic terms, asking participants to assess the layout's overall suitability for performing daily work tasks. As can be seen from the graph below (Figure 6.4), the results obtained clearly represent a hierarchy of preferences considering all the aspects previously mentioned.

The two scenarios characterized by high visual occlusion (scenarios 1 and 3) scored below the neutral threshold of the Likert scale ($M = 3.80$ and 3.70 , respectively). It is critically important that both an orthodox orthogonal office layout (scenario 1) and an organic, unconventional layout (scenario 3) are grouped within this low-preference category. In this regard, it can be concluded that, regardless of the architectural style employed, total visual isolation remains a factor perceived as detrimental to comfortable and productive work. In contrast, scenarios with open space and visual connectivity received the highest ratings. While the open-space orthogonal scenario (scenario 2) provides an acceptable baseline option ($M = 4.85$), the highest preferences are towards scenario 4 ($M = 5.40$). Although both share a high VO, scenario 2 imposes a significantly higher perceived cognitive load due to its rigid orthogonality, whereas the morphological fluidity of scenario 4 reduces mental effort. Therefore, the combination of fluid organic partitions and preservation of high visual

aperture (High VO) represents an optimal combination. The results obtained therefore confirm that the Activity-Based architectural approach, if adequately implemented in terms of volumetric proportions to avoid inhibiting wayfinding and interaction, not only reduces cognitive stress (§ 6.2.3) but also constitutes the layout in which users show the greatest propensity to work productively. In conclusion, while the standard open plan configuration (scenario 2) provides an acceptable starting point for modern office design, scenario 4 emerges as the only spatial configuration that users would reliably choose as an optimal daily workplace.

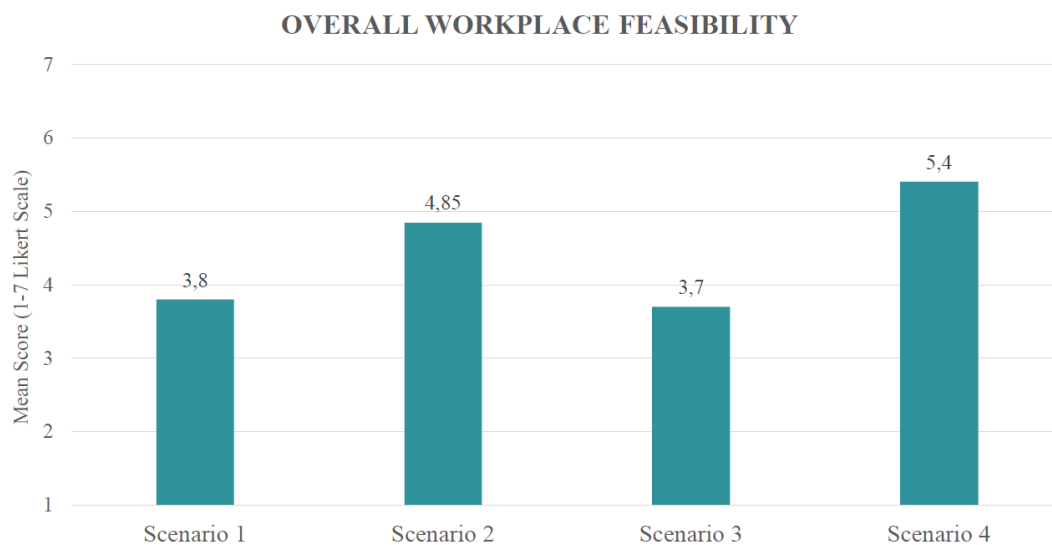


Figure 6.4: Mean score for overall workplace feasibility. The bar chart illustrates the participants' behavioural intent regarding the suitability of each architectural layout for performing daily work tasks. Error bars indicate ± 1 Standard Deviation. Source: [Author].

6.3 Objective EEG data

Due to motion artefacts inherent in MoBI EEG, the analysis focuses on qualitative pattern recognition rather than statistical inference. Implementing this dynamic approach in MR scenarios introduced significant methodological challenges regarding the management of muscle and ocular interference, as detailed in section 5.3. In line with the overall research objective of assessing the cognitive effect of the project in a non-clinical ecological context, neurophysiological assessment will depend on a thorough visual examination of EEG data in the time domain. To achieve maximum epistemological validity and avoid selection bias, the qualitative analysis will be limited to a subsample of five subjects (P07, P09, P15, P16, P17), isolated due to an optimal sensor impedance that can be established over all sessions.

6.3.1 Cognitive load and concentration (Frontal Theta)

Neuroergonomic literature believes that an increase in the level of cognitive load is associated with desynchronization and increased power of the Theta Frontal band (4-8 Hz) (Klimesch, 1999; Gevins & Smith, 2003). However, by directly examining the raw EEG tracings in the time domain, the analysis of the executive load on the frontal and prefrontal channels (AF3, AF4, F3, F4, F7, F8) focused on the observation of macro-variations in wave amplitude. For active spatial navigation activities, strong amplitude excursions in this area serve as highly reliable behavioural indicators of spatial disorientation (Gramann et al., 2011). These markers objectively document the massive visual exploration effort induced by the architectural layout, providing a tangible picture of the overall cognitive load (Banaei et al., 2017).

Visual inspection indicated a consistent pattern across subjects, capable of reliably triangulating the mental workload recorded in the questionnaires (Section 6.2). Figure 6.5 shows the tracings of participant 07 (P07), selected as a pragmatic case (Hero Image) for the visual clarity of his neurobehavioral response in all four experimental quadrants.

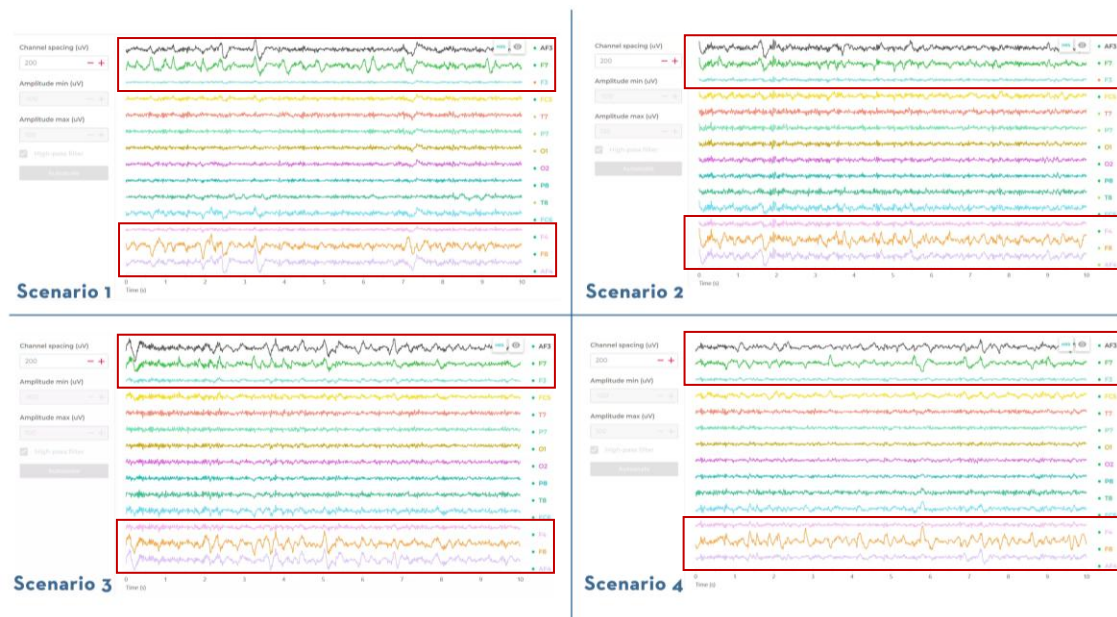


Figure 6.5: Raw time-domain EEG traces of participant 07 (P07) during the four experimental scenarios. Note the visible amplitude increase in the frontal channels (especially AF3, F7) in scenario 3 compared to the baseline, which is then resolved in scenario 4. Source: [Author]

Analysis of the P07 in the **Baseline (scenario 1: Low VO/Low PC)** shows a pattern of controlled and regular wave amplitude variations. The limited influence of the visual conditions predicted by the geometry of the orthogonal and closed corridor helps to reflect a baseline corresponding to ordinary executive activation, consistent with the reported mean mental effort score.

The transition to the **Open space (scenario 2: High VO/Low PC)** induces a visible increase in the frontal trace and the number of signal oscillations. Removing the top partitions allows you to expand the field of view (high Prospect) but eliminates the sense of protection (low Refuge). The study suggests that the subject is forced to continuously inhibit possible peripheral stimuli along the entire depth of the open space, which increases his visuomotor hypervigilance, reconfirming the criticalities associated with open plan.

The most pronounced neurological reaction recorded was highlighted in scenario 3 (**Low VO/High PC**). The oscillations of the P07 signal show erratic peaks that saturate the amplitude scale. Architecturally, this anomalous effect can be interpreted as a response to an acute feeling of spatial disorientation caused by the absence of deep visual axes in combination with the irregular and curved boundary lines of the walls, which block Wayfinding Legibility. The individual is forced to continue visual search to try to identify the nature of the surrounding space, physiologically translating the peaks in mental fatigue documented in the questionnaire (see §6.2.3).

Finally, the analysis of scenario 4 (**High VO/High PC**) resolves the geometric paradox (H3). Although the partitions maintain their irregular zigzag structure, increased visibility (High VO) has brought the front track of P07 to a state of rest. The ability to anchor the gaze to the geometric grid structure of the building in the distance reduces the feeling of disorientation. The evident stabilization of the neurophysical signal objectively demonstrates that the complexity of the geometry, when accompanied by high visibility, favors the Ease of Mind state declared by the participants.

As highlighted in Table 6.2, this neurological progression was repeated systematically and unequivocally in the entire qualitative subsample.

Participant	Scenario1	Scenario 2	Scenario 3	Scenario 4
P07	Stable and rhythmic fluctuation	Increased signal density (hyper-vigilance)	Massive and erratic spikes	Flat and relaxed trace
P09	Measured signal (routine)	Increased amplitude and frequency	Maximum frontal fragmentation	Clear reduction in chaotic activity
P15	Rhythmic	Greater signal thickness on AF3/F7	Continuous tension and repeated spikes	Regular and relaxed pattern
P16	Optimal baseline control	Visible attentional effort	Excursions beyond the scale limit	Regularity surpassing scenario 2
P17	Moderate baseline	Heightened peripheral activation	Signal saturation due to spatial stress	Minimal activity

Table 6.2: Qualitative matrix of frontal activation. Summary of inter-subject visual inspection.

6.3.2 Visuospatial stress (*Parieto-Occipital Alpha*)

In the context of neuroergonomy, parieto-occipital cortex activity is closely related to visual perception and egocentric mapping of the environment (Plank, Müller, Onton, Makeig, & Gramann, 2010; Lin, Chiu, & Gramann, 2015; Bu-Omer, Gofuku, Sato, & Miyakoshi, 2021). Participant observation 07 (P07), regarding the rear sensors P7, P8, O1 and O2, shows observable differences in four scenarios, useful for understanding how the architectural configuration influences the ease or difficulty of topological reading of space (Figure 6.6).

In the baseline (scenario 1), the back track appears more stable and regular, suggesting a relatively simple exploration condition. In scenario 2, the posterior trace remains legible but shows greater irregularity, which corresponds to a greater opening of the space and requires more continuous control of the numerous peripheral stimuli.

Scenario 3, in fact, appears more irregular, but without therefore constituting a break compared to the other scenarios for P07. For this reason, the most evident

6.4 Discussion and neuroergonomic triangulation

One of the most evident convergences between subjective and objective data is found during the analysis of spatial extremes. The environment described in scenario 3 (Labyrinth: Low VO/High PC) is perceived as causing the greatest mental

exhaustion, frustration, and disorientation, according to the questionnaires. These strong subjective negative emotions are reliably confirmed by EEG data, indicating a greater number of track irregularities in the frontal areas of the brain, which implies an intense perceptual and cognitive search for the optimal path. Back tracings show more unstable patterns, which is a direct indicator of spatial mapping overhead. This evidence allows us to affirm that complex geometry, together with total visual occlusion, acts as an intense cognitive stressor that prevents Wayfinding Legibility.

In contrast, data on scenario 4 (High VO/High PC) successfully resolve the initially hypothesized geometric paradox (H3). According to psychometric measurements, this spatial environment was rated as the best in terms of mental ease, minimal cognitive load, and overall task feasibility ($M = 5.40$). This subjective positive perception is reflected by neurophysiological data, which explains how, despite the irregular zigzag spatial configuration that is not standardized, the restoration of visual depth (high Prospect) leads to the stabilization of EEG tracings. The signals return to the stable and calm position, like the basic conditions of the closed corridor.

In conclusion, this triangulation serves as empirical architectural evidence: spatial complexity is not inherently stressful, but the lack of visual openness turns an irregular layout into a cognitive trap. When the architectural design provides broad visual permeability, allowing users to anchor their gaze to distant structural elements and anticipate their own movement, even highly articulated environments cease to be a threat. On the contrary, they foster a state of spatial comfort and mental relaxation, offering a scientifically validated alternative to the oppressive monotony of traditional orthogonal grids. Both subjective and neurophysiological data consistently indicate increased cognitive effort in high-complexity enclosed environments.

7. EVIDENCE-BASED DESIGN APPLICATION

7.1 From experimental data to architectural concept

The process of deriving architectural solutions based on neurophysiological findings represents the main operational phase of this research. The results presented and discussed in Chapter 6 translate into a neuroergonomics-based redesign solution aimed at modifying floor G of the building known as “La Nave” in Pavia, in order to allow the creation of an environment capable of positively influencing the cognitive functioning of its occupants.

The combined analysis of EEG and psychometric data confirms the fact that the current Taylorist model, represented by blind corridors and cellular partitions like scenario 1 (Low VO / Low PC), promotes sensory deprivation and proxemic rigidity. At the same time, the simple absence of physical barriers leading to a conventional open plan, like scenario 2 (High VO / Low PC), indicates the development of peripheral hypervigilance and perceptual vulnerability. Considering the results described above, the architectural proposal considers scenario 4 (High VO / High PC), since in this case, geometric complexity is no longer perceived as visuospatial stress due to the high visual permeability.

To contextualize the project within Giancarlo De Carlo's architectural framework, adhering to the neuroergonomic specifications developed by the experiments, the proposal is carefully structured on the following four Post-Experiment Design Guidelines taken directly from the Mixed Reality experiment:

- **Reducing visual occlusion and maximising Prospect:** The project requires the absence of full-height opaque walls. The walls separating the interior spaces cannot exceed a maximum height of 1.20 meters, allowing the standing user to have the visual perspective to dominate the entire space, thus facilitating navigation and orientation (wayfinding) and reducing spatial anxiety.
- **Breaking the orthogonal grid and controlled increase of complexity:** By abandoning Taylorist rectangular layouts, the proposal aims to introduce organic shapes or irregular geometries to increase edge density and provide cognitive activation without leading to sensory deprivation, thus avoiding spatial monotony. Contrary to the commonly observed phenomenon of

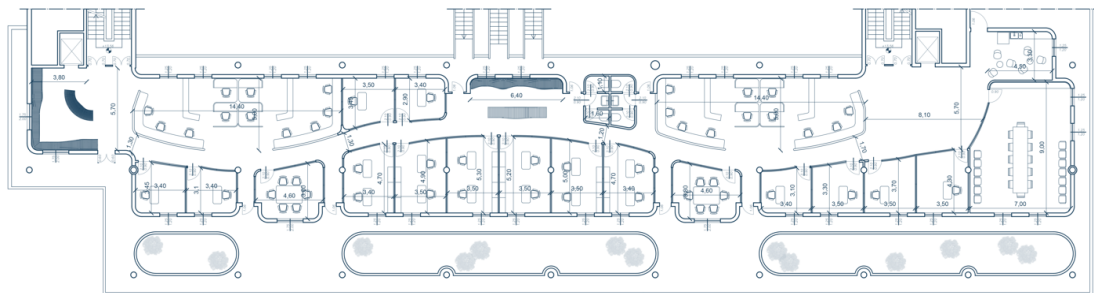
possible disorientation related to the introduction of organic curves, the current design exploits low physical barriers that ensure wide visibility throughout the space.

- **Defining proxemic anchors and group protection:** The project avoids using the open-plan format and creates shelters by using irregular geometries of low physical barriers that can create niches and corners that protect workers in their work area from peripheral hypervigilance.
- **Resolution of the labyrinth paradox and balance of variables:** The new project is committed to not introducing high morphological complexity into any blind or closed space. Geometric complexity is neuroergonomically valid only when anchored to deep peripheral visibility.

7.2 Cognitive-Based Zoning

Overcoming the functional fragmentation paradigm, traditionally based on real estate efficiency criteria, corporate hierarchies, and acoustic and environmental restrictions, requires a reformulation of space as a function of actual cognitive load variability. Within floor G of "La Nave", the plan becomes a neuroergonomic ecosystem, where each individual area is positioned and proportioned in such a way as to provide opportunities responsive to specific cognitive needs: concentrative execution, informal collective interactions, and attentional recovery.

Architecture thus takes an active role. It is no longer just a space that simply hosts work functions passively, but the space itself guarantees a set of complementary environments to allow workers to migrate to self-regulate their neurobiological rhythms, supporting the neurocognitive and attentional variations that characterize the day of the contemporary knowledge worker.



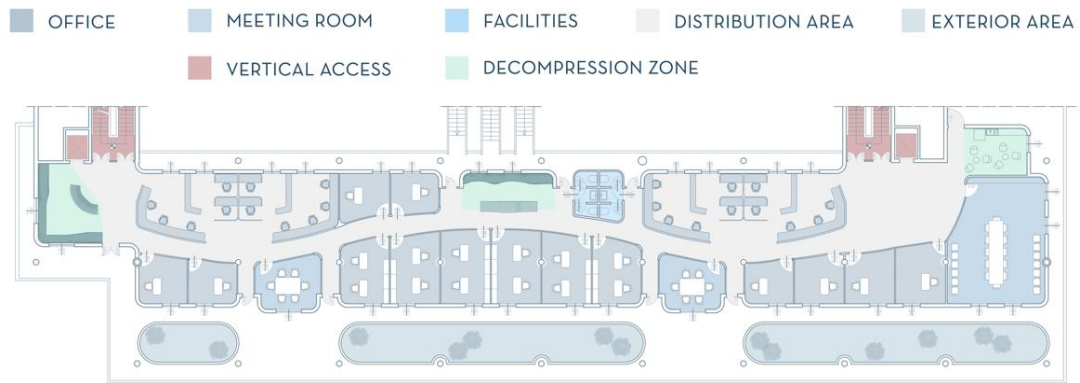


Figure 7.2: Function diagram of proposed layout. Source: [Author].

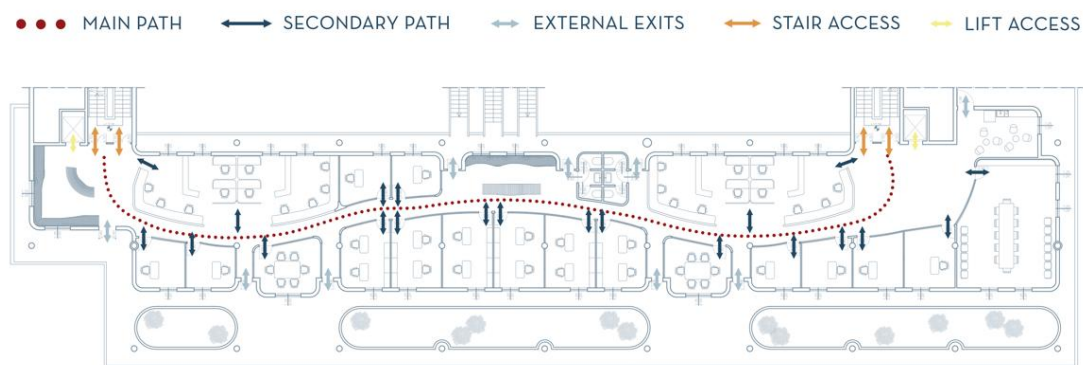


Figure 7.3: Flow diagram of proposed layout. Source: [Author].

7.2.1 *Transparent cellularity for focal work*

Although the primary focus of this study lies in exploring the neuropsychological processes of active movement through public areas, the regeneration of such areas requires a thorough review of private workstations. The macro-areas designated for high-intensity individual cognitive work and teamwork have been modified to provide the functionality required by the Directed Attention system, without affecting the visual permeability of the entire system. Therefore, the need to combine both elements became the basis of the transparent cellularity approach used in all linear and curved blocks of the project.

In particular, the focused work area is configured as a physically delimited environment, divided into two distinct bands. First, the lower band consists of a continuous opaque base that rises 1.20 meters above floor level, thus performing two main functions: protecting the shoulders of the seated worker, mitigating the exposure of visual clutter on desks, and screening the lower peripheral movements that constitute a primary source of distraction in the low visual field.

The upper band, which rises above the opaque partition up to the intrados of the

ceiling, is made of laminated acoustic glass. As a result, the offices are soundproofed for individual concentration, remaining visually transparent. Such an approach offers an important advantage: sound insulation is maintained, allowing employees to focus on their work and allowing corridor users to perceive spatial depth and orient themselves without difficulty.

7.2.2 Decompression zone and attentional restoration

A performance-oriented workplace, considered as a system that combines private and public workspace, cannot rely solely on immediate productivity. Intensive periods of work will alternate with the psychological breaks necessary to prevent and mitigate Directed Attention Fatigue (DAF).

In this context, the solution consists of reserving specific places for mental restoration, according to the criteria of Attention Restoration Theory (ART). To avoid the negative effects of overlaps, these decompression areas, located around the perimeter and in the central islands distant from the operational clusters, will be appropriately positioned outside the primary circulation nodes.

Their configuration favors fluid and informal microenvironments, where the combination of curved furniture, optical apertures, and indirect biophilic calls contributes to a soft fascination situation. In this way, the cognitive system is offered a space for psychological rebalancing that meets the requirements of ART, without interrupting overall continuity and functionally separating rapid pedestrian flows from regenerative rest areas.

7.3 Neuro-sensory materiality and environmental control

The geometric validation of the layout alone is insufficient to guarantee the project's neuroergonomic coherence. To ensure that the spatial performance observed analytically materialises in concrete experience, the principles of Evidence-Based Design must be translated into precise material, technological, and constructional choices.

The environment's perceptual quality relies upon the interplay of form, materials, acoustics, surfaces, and lighting. From this perspective, the design for “La Nave” integrates the control of environmental stimuli as a fundamental component of its cognitive support strategy.

7.3.1 Chromatic orientation and neuro-illuminotechnical control

Compared to the Brutalist aesthetic style of architect Giancarlo De Carlo, the chromatic project makes use of the characteristic hues of "La Nave", centred on red and blue, reassigning it an active neuroergonomic role. The structural pillars, highlighted in red, act as a visual anchor in the fluidity of the space. According to the wayfinding literature, in fact, it demonstrates that vertical elements with high chromatic salience facilitate the formation of cognitive maps by the user, avoiding loss of orientation (Lynch, 1964). Similarly, the use of blue in full-height septa uses colour psychology to introduce calm-inducing backgrounds that lower arousal levels.

This balance is then consolidated by a rigorous lighting control, in which there is the integration of natural and artificial light. Indeed, attentional retrieval areas are oriented towards perimeter windows to maximize the positive effect of daylight required for circadian rhythms and cognitive performance (Boubekri, et al., 2014; Boubekri et al., 2020). The indoor rooms dedicated to work, on the other hand, are equipped with an artificial lighting solution with indirect and dimmable light (Tunable Lighting). In the areas dedicated to focused work, there is the adoption of cold colour temperatures (above 4000 K) and a high intensity to stimulate executive conceptualization, while in circulation flows and decompression areas, the chromatic temperature drops towards warmer hues (less than 3000 K), reducing glare and limiting fatigue of the prefrontal cortex (MG et al., 2019).

7.3.2 Integrated acoustic and material biomimicry

Controlling the allostatic load induced by sound disturbances results in specific design choices for the structural cladding. Resilient PVC continuous flooring plays the crucial role of mitigating footfall noise, thereby eliminating the problem of noise pollution that forces the brain to continuously and unintentionally filter out noise.

In elevation, the perceived hardness of the parapets clad in fiber cement with an exposed concrete finish, a material choice that honours the building's original architectural language, is balanced using wood. In particular, the dry-built dividing parapet is covered with micro-perforated wood panels, effective in absorbing medium-frequency sounds, such as speech (Frontczak et al., 2012). In decompression zones, the inclusion of fluid furniture and wooden seats introduces a biophilic texture into the spaces, where the natural fractal complexity of the grain alleviates the

alienation of the workspace and generates balanced tactile and visual stimulation (Taylor, 2006).

Sound insulation on the upper horizontal plane is ensured by the inspectable sound-absorbing ceiling made of hidden-edge mineral fibre. This technological decision, widely adopted in industry standards, ensures maximum sound absorption with high noise reduction (NRC), masking the metal frame grid. Furthermore, the ceiling covering is intended to create a flat surface, which optimises the reflection of indirect artificial light without visually fragmenting the spatial volume.

7.4 Parametric validation of the proposed layout

It is in the final stage of the design process that the developed spatial configuration must be analysed according to the same parametric measurement approach used in virtual scenario analysis (see Chapter 6). For this reason, the project will be verified as a configuration capable of effectively meeting the neuroergonomic criteria defined through the experiment.

For this verification, two primary parameters must be considered: Visual Openness, measured using Isovist, and Perceived Complexity, measured using the Edge Density method. In addition to these measurements, and in accordance with realistic considerations regarding architectural construction, a real estate trade-off analysis will also be carried out. The aim is to verify whether the proposed configuration reflects, in its constructed version, the optimal compromise identified in Scenario 4.

7.4.1 Recalculating Visual Openness (VO)

To verify the effectiveness of the transparent cell paradigm (Section 7.2.1), the proposed layout was tested by 2D multidirectional isovist extraction (360°). According to the experiment, the algorithmic cutting plane was aligned to the user's standard eye height (1.65 m).

Three Vantage Points representative of the primary circulation axes were selected. The results provided a mean visible area index of 3,965 and a mean visual perimeter of 80.30, which, interpreted in terms of topological measures of visual magnitude, denote a substantial extension of the perceptual field across the proposed layout. Furthermore, the Mean Visual Depth indicator, which takes on an average value of

1,622, suggests the possibility of perceiving space through only a few visual steps and that perceptual orientation is immediate.

Along with a large extension of the visual perception space, the results include an indicator of Occlusivity with a mean value of 0.88. The value reflects the high degree of openness of the space, despite the presence of numerous hidden margins created by the curved walls. This results in a significant neuroergonomic balance: the environment avoids the oppressive closure of traditional cellular systems by simultaneously introducing a component of Mystery (Kaplan & Kaplan, 1989) capable of stimulating exploration without compromising spatial readability.

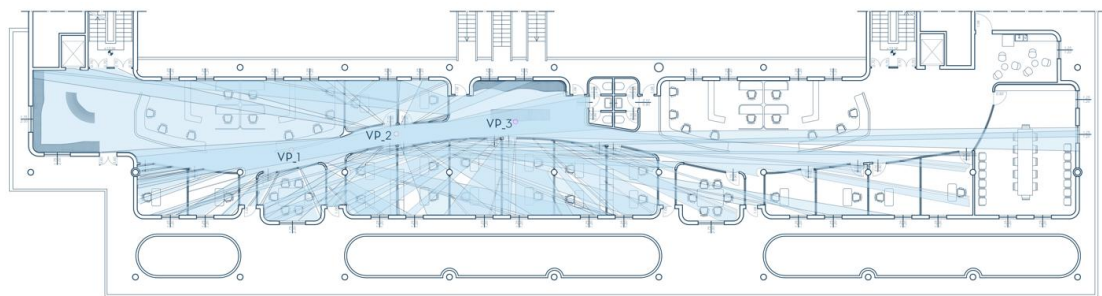


Figure 7.4: Isovist analysis of proposed layout. Source: [Author]

VP	Area	Perimeter	Mean Visual Depth
1	4,027	83,208	1,600
2	4,171	79,440	1,633
3	3,698	78,255	1,633
<i>Mean values</i>	3,965	<i>80,301</i>	<i>1,622</i>

Table 7.1: Parametric validation certifies the success of the Evidence-Based Design intervention. The balance between extensive visual perimeter (80.3 m) and the deep Occlusivity (0.88) demonstrates the physical achievement of the optimal cognitive parameters, successfully preventing both sensory deprivation and visual overload.

7.4.2 Recalculating Perceived Complexity (PC)

The second parameter used to evaluate the layout is the Perceived Complexity, measured using the Edge Density. The design goal was to create sufficient morphological articulation to counteract the perceived simplicity of the Taylorist model, without resorting to an overly fragmented scheme.

This assessment was achieved by taking three high-resolution perspective frames at the same points used for the Isovist assessment. The images were computationally processed to calculate the ratio of high-contrast edge pixels to all pixels in the image. The results show an average edge density of 3%. In particular, the lateral observation points maintain a constant value of 2%, while the central nodes reach a density of 4%, corresponding to a higher density of curved partitions. This profile is consistent with the project's distributional logic: decompression areas preserve high readability, while central areas are characterized by higher levels of complexity without reaching the overload point. Partition sinuosity and material biometrics overcome the original visual monotony while preserving sufficient order not to divert cognitive resources.

VP	Pixel tot. (1920x1080)	Edge pixels	Edge density
1	2.073.600	43.555	2,1005
2	2.073.600	72.999	3,5204
3	2.073.600	43.158	2,0813
			2,567

Table 7.2: Computational analysis confirms the success of the geometric and material strategy. The mean Edge Density of 3% represents the ideal neuroergonomic threshold, introducing sufficient visual complexity to sustain active attention whilst preventing the cognitive overload typical of fragmented environments.

7.4.3 Comparative analysis of surfaces (real estate trade-off)

As anticipated by the project guidelines, the expansion of circulation routes and the inclusion of decompression areas require a mandatory assessment regarding the issue of real estate effectiveness and the ratios of available space for desks. To make this spatial transition transparent and theoretically justified, a comparative analysis was conducted (Table 7.3) based on the total surface area of 640 m² on floor G of the "La Nave" building.

SPATIAL METRIC	EXISTING LAYOUT	PROPOSED LAYOUT
<i>Total floor area</i>	640,00 sqm	640,00 sqm
<i>Circulation & public space</i>	113,00 sqm	212,40 sqm
<i>Individual workspace</i>	427,60 sqm	417,50 sqm
<i>Maximum occupancy (desks)</i>	33 workspace	44 workspace
<i>Workspace footprint</i>	13,00 sqm/person	9,5 sqm/person

Table 7.3: The reduction of massive structural partitions has allowed for the recovery of useful space, allowing the proposed layout to significantly expand circulation areas and increase the total capacity of the workstations without altering the overall footprint of the building.

The dimensional analysis shows that the proposed layout refutes the presumption that the expansion of common spaces leads to the creation of oppressive spaces in offices. By reducing the footprint of existing walls (which previously required almost 100 m²), it was possible to recover a significant useful surface area. In this way, the net square meters used for regenerative circulation have been almost doubled.

Despite the evident quantitative decline in functional area per capita (from 13.0 m² to 9.5 m², remaining fully compliant with the Italian Legislative Decree 81/08 and local health authority ergonomic guidelines), this decline represents a deliberate and theoretically well-founded spatial trade-off. Apparent physical densification does not translate into psychological oppression for two fundamental reasons:

1. **The dissociation between physical containment and visual expansion:** oppressive sensations emerge in conventional offices due to the occlusive nature of the opaque walls that confine the gaze. In contrast, applying the principles of the “transparent cellularity” paradigm in design, the boundaries of the upper band of offices are made of acoustic glass. This technique ensures that the user has a visual expansion (Prospect) that encompasses the entire area, even if it is in its place. Therefore, in the proposed layout, the floor area of 9.5 m² per capita will only serve the function of providing a physically and acoustically confined shelter space, while the person's cognitive system will perceive it as unlimited, thus cancelling out any sensation related to claustrophobia or constraint.
2. **Overcoming the desk-centric model:** Evaluating the quality of a workspace based solely on the size of a single desk is a legacy of the Taylorist model, now obsolete due to the dynamics of contemporary knowledge work. As a

result, square meters previously occupied by private spaces will be consciously redistributed in favor of expanding public spaces. This decision will greatly improve the quality of the environment as pathways and transition areas become active zones that promote spontaneous communication, physical movement, and attention restoration (ART).

In summary, while the decrease in personal area can be seen as a reduction, it is largely offset by the creation of a neuroergonomic public space capable of absorbing cognitive fatigue, reducing the invisible costs associated with spatial stress that traditional models tend to ignore.

7.4.4 Conclusion of the design phase

The quantitative validation of the geometry of the proposed layout consistently concludes the research methodology. The combination of Visual Openness analysis, Perceived Complexity, and surface optimization confirms how the concept used for floor G of "La Nave" physically translates the neuroarchitectural principles emerging from the experimental analysis. The retrofit intervention demonstrates how architectural design, if built on empirical foundations, can serve as an active infrastructure to support cognitive well-being, transforming real estate densification into an enhancement of human performance.

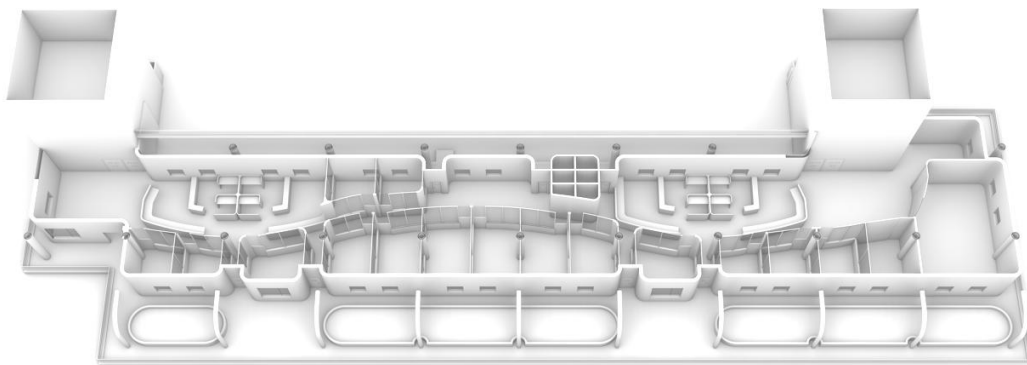


Figure 7.5: 3D model of proposed layout. Source: [Author]

8. CONCLUSIONS AND FUTURE DEVELOPMENTS

8.1 Response to research questions and summary of results

This research investigated the extent to which spatial configurations within the work environment influence the cognitive load and neurobiological balance of occupants. By testing the original hypotheses, it becomes possible to confirm theoretical predictions and demonstrate the inefficiency of today's main spatial models.

The hypothesis that closed cellular layouts (scenario 1) generate a stimulation deficit was validated by EEG tracings, which recorded a decrease in cortical activation attributable to sensory deprivation. In contrast, the pure open plan layout (scenario 2) consistently triggered states of hypervigilance and continuous stress, resulting from the complete absence of proxemic protection or Refuge. The answer to the central research question emerges from the data collected in scenario 4: neuroergonomic optimization of public and circulation areas requires a precise balance between visual permeability (High VO) and controlled morphological complexity (High PC).

The subsequent application of these parameters to the case study of floor G of "La Nave" demonstrates the operational validity of the Evidence-Based Design methodology. Moving beyond formal arbitrariness, biometric data have successfully guided the transparent cellularity paradigm, generating an architectural ecosystem in which operational areas support directed attention, while public areas facilitate systematic cognitive restoration. As highlighted, the value of this study lies not in the formulation of universal scientific laws but in the validation of a design process: the neuroarchitectural approach proves to be an exceptional practical tool for allowing architects to decipher space, identify invisible neuroergonomic critical issues, and develop design strategies anchored to objective parameters.

8.2 Study limitations and uninvestigated variables

Despite the strong consistency between experimental data and subsequent spatial choices, it is necessary to recognize the structural limitations of this research. The value of this study, in fact, lies not in the formulation of universal rules of thumb but

in the exploration of a new neuroarchitectural method to support the design process. From this perspective, the critical issues that emerged during the validation of the protocol highlight three main methodological limitations:

- 1. Geometric isolation and exclusion of multisensory variables:** a first methodological limitation concerns the exclusion from the Mixed Reality (MR) experiment of elements fundamental to architectural perception: materials, lighting, colours, and furnishing details. This limitation did not arise from an underestimation of their importance, but rather from a rigorous experimental necessity. To ensure the reliability of the electroencephalographic (EEG) tracing, it was essential to prevent the introduction of confounding visual variables. The use of a grayscale model allowed us to isolate pure geometry (through Visual Openness and Edge Density metrics), electing it as a fundamental entry point of the neuroarchitectural method. These material and chromatic dimensions, although essential for environmental comfort and allostatic load mitigation, were found to have their correct and complete application exclusively in the subsequent design phase (Chapter 7) but remained excluded from real-time biometric validation.
- 2. Absence of a longitudinal survey of work efficiency:** A second significant limitation concerns the spectrum of human performance measurement. The experimental protocol focused exclusively on recording the levels of arousal and proxemic stress generated during active space exploration (transit in public areas and corridors). Consequently, the research lacks a comparative experiment on work efficiency before and after spatial retrofit intervention. Since it did not measure stationary productivity at the desk, the study cannot provide direct statistical correlations between layout changes and the actual increase in long-term executive performance, leaving this demonstration to future developments in the discipline.

These limitations are ultimately compounded by the perimeter of the reference sample. Scenario optimization was calibrated to the reactions of neurologically standard users. Consequently, the identified optimal thresholds (3% for Edge Density and 0.88 for Occlusion) may not cover the needs of the broad spectrum of

neurodiversity, requiring specific investigations and parametric adaptations in the future for subjects with different attentional sensitivities.

8.3 Future developments and disciplinary perspectives

The limitations found reflect the embryonic stage of a relatively recent field of study. The hybridization of applied neuroscience, biometric instrumentation, and immersive simulation currently represents a methodological frontier subject to technological constraints.

The lack of empirical data on work productivity, identified as the main limitation of this study, outlines the necessary future development of the research. The next step will require the implementation of validated cognitive tests, such as the Stroop Test or Working Memory measurements, to be administered to experimental subjects before and after exposure to the optimized layouts. This integration will allow us to unambiguously correlate spatial stress relief with a measurable increase in executive efficiency.

In parallel, the continued advancement of Mixed Reality technologies and wearable EEG sensors will enable complex multisensory experimentation, simultaneously sampling cortical reactions to visual, acoustic, and thermodynamic stimuli. Furthermore, the ability to collect neurophysiological big data will facilitate the mapping of spatial requirements associated with neurodiversity, moving the discipline towards a truly inclusive design capable of adapting to different sensitivities.

In conclusion, the systematic adoption of Evidence-Based Design demonstrated in this thesis anticipates a profound paradigm shift. As investigative tools become more accessible, neurophysiological evidence-based design will move from niche experimentation to standard practice, establishing itself as the most rigorous methodology for designing spaces capable of actively protecting human cognitive, emotional, and biological well-being.

Reference list

- [1]. Allen, T., & Henn, G. (2007). *The Organization and Architecture of Innovation*. Routledge. Retrieved from <https://www.perlego.com/book/1626301/the-organization-and-architecture-of-innovation-pdf>
- [2]. Appel - Meulenbroek, H. A. J. A., Groenen, P. J. M., & Janssen, I. I. (2011). An end users perspective on activity-based office concepts. *Journal of Corporate Real Estate*, 13(2), 122–135. <https://doi.org/10.1108/14630011111136830>
- [3]. Appleton, J. (1975). *The experience of landscape*. London, New York, Wiley. Retrieved from <http://archive.org/details/experienceofland00appl>
- [4]. Banaei, M., Hatami, J., Yazdanfar, A., & Gramann, K. (2017). Walking through Architectural Spaces: The Impact of Interior Forms on Human Brain Dynamics. *Frontiers in Human Neuroscience*, 11, 477. <https://doi.org/10.3389/fnhum.2017.00477>
- [5]. Banbury, S., & Berry, D. (2005). Office noise and employee concentration: Identifying causes of disruption and potential improvements. *Ergonomics*, 48(1), 25–37. <https://doi.org/10.1080/00140130412331311390>
- [6]. Benedikt, M. L. (1979). To Take Hold of Space: Isovists and Isovist Fields. *Environment and Planning B: Planning and Design*, 6(1), 47–65. <https://doi.org/10.1068/b060047>
- [7]. Berlyne, D. E. (1971). *Aesthetics and psychobiology*. New York, Appleton-Century-Crofts. Retrieved from <http://archive.org/details/aestheticpsycho0000berl>
- [8]. Boubekri, M., Cheung, I. N., Reid, K. J., Wang, C.-H., & Zee, P. C. (2014). Impact of Windows and Daylight Exposure on Overall Health and Sleep Quality of Office Workers:

- A Case-Control Pilot Study. *Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine*, 10(6), 603–611.
<https://doi.org/10.5664/jcsm.3780>
- [9]. Boubekri, M., Lee, J., MacNaughton, P., Woo, M., Schuyler, L., Tinianov, B., & Satish, U. (2020). The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers. *International Journal of Environmental Research and Public Health*, 17(9), 3219. <https://doi.org/10.3390/ijerph17093219>
- [10]. Briesemeister, B. B., Tamm, S., Heine, A., & Jacobs, A. M. (2013). Approach the Good, Withdraw from the Bad—A Review on Frontal Alpha Asymmetry Measures in Applied Psychological Research. *Psychology*, 4(3), 261–267.
<https://doi.org/10.4236/psych.2013.43A039>
- [11]. Bu-Omer, H. M., Gofuku, A., Sato, K., & Miyakoshi, M. (2021). Parieto-Occipital Alpha and Low-Beta EEG Power Reflect Sense of Agency. *Brain Sciences*, 11(6), 743.
<https://doi.org/10.3390/brainsci11060743>
- [12]. Canny, J. (1986). A Computational Approach to Edge Detection. *IEEE Trans. Pattern Anal. Mach. Intell.*, 8(6), 679–698. <https://doi.org/10.1109/TPAMI.1986.4767851>
- [13]. Colombo, Fausto, Di Mambro, Antonio, & Kato, Akinori. (1977). *Piano di sviluppo e ristrutturazione dell'Università di Pavia, 1972-75*. 41(423), 56–57.
- [14]. Danielsson, C. B., & Bodin, L. (2008). Office type in relation to health, well-being, and job satisfaction among employees. *Environment and Behavior*, 40(5), 636–668.
<https://doi.org/10.1177/0013916507307459>
- [15]. Davidson, R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain*

- and Cognition*, 20(1), 125–151. [https://doi.org/10.1016/0278-2626\(92\)90065-T](https://doi.org/10.1016/0278-2626(92)90065-T)
- [16]. Diarra, M., Theurel, J., & Paty, B. (2025). Systematic review of neurophysiological assessment techniques and metrics for mental workload evaluation in real-world settings. *Frontiers in Neuroergonomics*, 6. <https://doi.org/10.3389/fnrgo.2025.1584736>
- [17]. Duffy, F. (1997). *The new office*. London: Conrad Octopus. Retrieved from <http://archive.org/details/newoffice0000duff>
- [18]. Eaton, K. (2026, February 26). Open-Plan Offices Could Be Hurting Employees' Brains, New Research Suggests. Retrieved 24 May 2026, from Inc website: <https://www.inc.com/kit-eaton/open-plan-offices-could-be-hurting-employees-brains-new-research-suggests/91308620>
- [19]. Eberhard, J. P. (2008). *Brain Landscape The Coexistence of Neuroscience and Architecture*. Oxford, New York: Oxford University Press.
- [20]. Enhesa. (2024). The price of productivity loss. Retrieved 16 March 2026, from Enhesa website: <https://www.enhesa.com/resources/article/what-is-presenteeism-the-price-of-productivity-loss/>
- [21]. European House Ambrosetti & Angelini Pharma. (2023). *Headway 2023—Mental Health Index*.
- [22]. Evans, G. W., & Johnson, D. (2000). Stress and open-office noise. *Journal of Applied Psychology*, 85(5), 779–783. <https://doi.org/10.1037/0021-9010.85.5.779>
- [23]. Frontczak, M., Schiavon, S., Goins, J., Arens, E., Zhang, H., & Wargocki, P. (2012). Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor

- environmental quality and building design. *Indoor Air*, 22(2), 119–131.
<https://doi.org/10.1111/j.1600-0668.2011.00745.x>
- [24]. Gevins, A., & Smith, M. E. (2003). Neurophysiological measures of cognitive workload during human-computer interaction. *Theoretical Issues in Ergonomics Science*, 4(1–2), 113–131. <https://doi.org/10.1080/14639220210159717>
- [25]. Graham, L. T., Parkinson, T., & Schiavon, S. (2021). Lessons learned from 20 years of CBE's occupant surveys. *Buildings & Cities*, 2(1). <https://doi.org/10.5334/bc.76>
- [26]. Gramann, K., Gwin, J. T., Ferris, D. P., Oie, K., Jung, T.-P., Lin, C.-T., ... Makeig, S. (2011). Cognition in action: Imaging brain/body dynamics in mobile humans. *Reviews in the Neurosciences*, 22(6), 593–608. <https://doi.org/10.1515/RNS.2011.047>
- [27]. Grimshaw, G. M., & Carmel, D. (2014). An asymmetric inhibition model of hemispheric differences in emotional processing. *Frontiers in Psychology*, 5, 489. <https://doi.org/10.3389/fpsyg.2014.00489>
- [28]. Hamilton, D. K., & Watkins, D. H. (n.d.). *Evidence-Based Design for Multiple Building Types*.
- [29]. Harmon-Jones, E., Gable, P. A., & Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology*, 84(3), 451–462. <https://doi.org/10.1016/j.biopsycho.2009.08.010>
- [30]. Hemp, P. (2004). Presenteeism: At work--but out of it. *Harvard Business Review*, 82(10), 49–58, 155.
- [31]. Higuera-Trujillo, J. L., Llinares, C., & Macagno, E. (2021). The Cognitive-Emotional Design and Study of Architectural Space: A Scoping Review of Neuroarchitecture and Its

- Precursor Approaches. *Sensors*, 21(6), 2193. <https://doi.org/10.3390/s21062193>
- [32]. Hoendervanger, J. G., de Been, I., Van Yperen, N., Mobach, M. P., & Albers, C. (2016). Flexibility in use: Switching behaviour and satisfaction in activity-based work environments. *Journal of Corporate Real Estate*, 18(1), 48–62. <https://doi.org/10.1108/JCRE-10-2015-0033>
- [33]. Ioanni Delsante. (2007). *Giancarlo De Carlo and the faculty of engineering of Pavia*.
- [34]. Jung, C.-C., Liang, H.-H., Lee, H.-L., Hsu, N.-Y., & Su, H.-J. (2014). Allostatic Load Model Associated with Indoor Environmental Quality and Sick Building Syndrome among Office Workers. *PLoS ONE*, 9(4), e95791. <https://doi.org/10.1371/journal.pone.0095791>
- [35]. Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective* (pp. xii, 340). New York, NY, US: Cambridge University Press.
- [36]. Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, 15(3), 169–182. [https://doi.org/10.1016/0272-4944\(95\)90001-2](https://doi.org/10.1016/0272-4944(95)90001-2)
- [37]. Kiiski, H., Bennett, M., Rueda-Delgado, L. M., Farina, F. R., Knight, R., Boyle, R., ... Whelan, R. (2020). EEG spectral power, but not theta/beta ratio, is a neuromarker for adult ADHD. *The European Journal of Neuroscience*, 51(10), 2095–2109. <https://doi.org/10.1111/ejn.14645>
- [38]. Kim, J., & De Dear, R. (2013). Workspace satisfaction: The privacy-communication trade-off in open-plan offices. *Journal of Environmental Psychology*, 36, 18–26. <https://doi.org/10.1016/j.jenvp.2013.06.007>

- [39]. Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews*, 29(2), 169–195.
[https://doi.org/10.1016/S0165-0173\(98\)00056-3](https://doi.org/10.1016/S0165-0173(98)00056-3)
- [40]. Lee, K.-T., & Kim, J.-H. (2024). Relationship between psycho-physiological indicators and task performance under various indoor space designs for telecommuting environment by introducing mixed-reality. *Scientific Reports*, 14(1), 1977.
<https://doi.org/10.1038/s41598-024-52291-1>
- [41]. Libby Sander, T. C. (2026, February 22). Why your brain has to work harder in an open-plan office than private offices. Retrieved 24 May 2026, from Phys.org website:
<https://phys.org/news/2026-02-brain-harder-office-private-offices.html>
- [42]. Lin, C.-T., Chiu, T.-C., & Gramann, K. (2015). EEG correlates of spatial orientation in the human retrosplenial complex. *NeuroImage*, 120, 123–132.
<https://doi.org/10.1016/j.neuroimage.2015.07.009>
- [43]. Lombardia Beni Culturali. (2014). Piano di sviluppo e ristrutturazione dell'Università di Pavia—Polo Cravino—Pavia (PV) | Architettura in Lombardia dal 1945 ad oggi.
Retrieved 19 March 2026, from
<https://www.lombardiabeniculturali.it/architetture900/schede/p3010-00150/>
- [44]. Ltd, S. web team and C. S. (2024). An essential guide to reducing noise in open plan offices. Retrieved 16 March 2026, from Soundtect Website website:
<https://soundtect.com/our-latest-news-and-opinion/2024/an-essential-guide-to-reducing-noise-in-open-plan-offices/>
- [45]. Luck, S. J., & Kappenman, E. S. (Series Eds.). (2012). *The Oxford handbook of*

- event-related potential components* (pp. xxii, 641). New York, NY, US: Oxford University Press.
- [46]. Lynch, K. (1964). *The Image of the City*. MIT Press.
- [47]. Machado, P., Romero, J., Nadal, M., Santos, A., Correia, J., & Carballal, A. (2015). Computerized measures of visual complexity. *Acta Psychologica*, 160, 43–57.
<https://doi.org/10.1016/j.actpsy.2015.06.005>
- [48]. MG, F., J, H., M, K., K, K., Ms, R., & Bc, S. (2019, April 1). Circadian-Effective Light and Its Impact on Alertness in Office Workers. Retrieved 26 May 2026, from <https://stacks.cdc.gov>
- [49]. MiC, D.-D.-. (2024). Censimento delle architetture italiane dal 1945 a oggi. Retrieved 4 April 2026, from Censimento delle architetture italiane dal 1945 a oggi website: <https://censimentoarchitetture.cultura-gov.it/>
- [50]. Morrison, R. L., & Macky, K. A. (2017). The demands and resources arising from shared office spaces. *Applied Ergonomics*, 60, 103–115.
<https://doi.org/10.1016/j.apergo.2016.11.007>
- [51]. Oktavia, W. A., Setiani, O., & Joko, T. (2026). *Risk Factors Associated with Sick Building Syndrome Among Workers in High-Rise Office Buildings*. 8.
- [52]. Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97–113.
[https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)
- [53]. Pejtersen, J., Allermann, L., Kristensen, T. S., & Poulsen, O. M. (2006). Indoor climate, psychosocial work environment and symptoms in open-plan offices. *Indoor Air*, 16(5),

392–401. <https://doi.org/10.1111/j.1600-0668.2006.00444.x>

- [54]. Plank, M., Müller, H. J., Onton, J., Makeig, S., & Gramann, K. (2010). *Human EEG Correlates of Spatial Navigation within Egocentric and Allocentric Reference Frames* (C. Hölscher, T. F. Shipley, M. Olivetti Belardinelli, J. A. Bateman, & N. S. Newcombe, Eds). In (pp. 191–206). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-14749-4_18
- [55]. Prina. (2023, January 22). 19 Giancarlo De Carlo, Fausto Colombo, Antonio Di Mambro, Akinori Kato (con B. dell’Era, S. Wettstein, A. Faraggiana, G. Ottolini; strutture: V. Korach, impianti: Ebner spa), Piano di sviluppo e ristrutturazione dell’Università di Pavia, 1972-75. Retrieved 12 April 2026, from <https://www.wearch.eu/19-giancarlo-de-carlo-fausto-colombo-antonio-di-mambro-akinori-kato-con-b-dellera-s-wettstein-a-faraggiana-g-ottolini-strutture-v-korach-impianti-ebner-spa-piano-di-sviluppo/>
- [56]. Raufi, B., & Longo, L. (2022). An Evaluation of the EEG Alpha-to-Theta and Theta-to-Alpha Band Ratios as Indexes of Mental Workload. *Frontiers in Neuroinformatics*, 16. <https://doi.org/10.3389/fninf.2022.861967>
- [57]. Sailer, K., & Penn, A. (2009). Spatiality and transpatiality in workplace environments. *Sailer, K. and Penn, A. (2009) Spatiality and Transpatiality in Workplace Environments. In: Koch, D. and Marcus, L. and Steen, J., (Eds.) Proceedings of the 7th International Space Syntax Symposium. Royal Institute of Technology (KTH), Stockholm, Sweden, p. 95.*
- [58]. Saval, N. (2014). *Cubed: A secret history of the workplace*. New York : Doubleday. Retrieved from <http://archive.org/details/cubedsecrethisto0000sava>

- [59]. Seddigh, A., Jönsson, F. U., Danielson, C. B., Westerlund, H., & Berntson, E. (2015). The effect of noise absorption variation in open-plan offices: A field study with a cross-over design. *Journal of Environmental Psychology*, 44, 34–44. <https://doi.org/10.1016/j.jenvp.2015.08.004>
- [60]. Seppänen, O., & Fisk, W. J. (2001). Association of ventilation system type with SBS symptoms in office workers: SBS symptoms in office workers. *Indoor Air*, 12(2), 1–24. <https://doi.org/10.1034/j.1600-0668.2002.01111.x>
- [61]. Seppänen, O., & Fisk, W. J. (2002). Association of ventilation system type with SBS symptoms in office workers. *Indoor Air*, 12(2), 98–112. <https://doi.org/10.1034/j.1600-0668.2002.01111.x>
- [62]. Shemesh, A., Leisman, G., & Grobman, Y. J. (2026). Bridging Space Perception, Emotions, and Artificial Intelligence in Neuroarchitecture. *Brain Sciences*, 16(2), 131. <https://doi.org/10.3390/brainsci16020131>
- [63]. Stamps, A. E. (2002). Entropy, Visual Diversity, and Preference. *The Journal of General Psychology*, 129(3), 300–320. <https://doi.org/10.1080/00221300209602100>
- [64]. Sundstrom, E., Town, J. P., Rice, R. W., Osborn, D. P., & Brill, M. (1994). Office noise, satisfaction, and performance. *Environment and Behavior*, 26(2), 195–222. <https://doi.org/10.1177/001391659402600204>
- [65]. Surawattanasakul, V., Sirikul, W., Sapbamrer, R., Wangsan, K., Panumasvivat, J., Assavanopakun, P., & Muangkaew, S. (2022). Respiratory Symptoms and Skin Sick Building Syndrome among Office Workers at University Hospital, Chiang Mai, Thailand: Associations with Indoor Air Quality, AIRMED Project. *International Journal of*

- Environmental Research and Public Health*, 19(17), 10850.
<https://doi.org/10.3390/ijerph191710850>
- [66]. Taylor, R. P. (2006). Reduction of Physiological Stress Using Fractal Art and Architecture. *Leonardo*, 39(3), 245–251. <https://doi.org/10.1162/leon.2006.39.3.245>
- [67]. The inevitability of change—Leesman. (2023). Retrieved 16 March 2026, from <https://www.leesmanindex.com/review-articles/the-inevitability-of-change/>
- [68]. Ulrich, R. S. (1984). View Through a Window May Influence Recovery from Surgery. *Science*, 224(4647), 420–421. <https://doi.org/10.1126/science.6143402>
- [69]. Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, 11(3), 201–230.
[https://doi.org/10.1016/S0272-4944\(05\)80184-7](https://doi.org/10.1016/S0272-4944(05)80184-7)
- [70]. What Is Ergonomics (HFE)? | International Ergonomics Association. (n.d.). Retrieved 16 March 2026, from <https://iea.cc/about/what-is-ergonomics/>
- [71]. Workplace Wellbeing 360 Report 2025—Intellect | Modern-day Mental Healthcare For Asia. (n.d.). Retrieved 16 March 2026, from <http://wellbeing-apac-industries-intellect-report-2024>
- [72]. Zimring, C., Joseph, A., Nicoll, G. L., & Tsepas, S. (2005). Influences of building design and site design on physical activity: Research and intervention opportunities. *American Journal of Preventive Medicine*, 28(2 Suppl 2), 186–193.
<https://doi.org/10.1016/j.amepre.2004.10.025>

List of figures

Figure 1.1: The financial impact of presenteeism on employers' health-related costs. Productivity lost to presenteeism accounts for the vast majority (**63%**) of total costs, significantly overshadowing direct medical costs and traditional absenteeism. Source: [Reprinted from Hemp (2004, p. 54)]

Figure 1.2: Noise levels – importance and satisfaction. Leesman Index 2023. Source: [https://www.leesmanindex.com/the-leesman-review/the-inevitability-of-change/, last accessed 2026/03/16].

Figure 1.3: Systematic workflow linking architectural variables with quantifiable neural and behavioral outcomes. Source: [Author]

Figure 1.4: Relationship between workspace layout variables, neural responses, cognitive outcomes, and resulting design implications. Source: [Author]

Figure 1.5: Methodological flowchart illustrating the logical structure of the thesis. Source: [Author].

Figure 2.1: The Larkin Administration Building, designed by Frank Lloyd Wright (1904). The orthogonal arrangement of desks reflects the mechanistic approach of Taylorism, functioning as a managerial panopticon. Source: [Collection of The Buffalo History Museum. Larkin Company photograph collection, Picture. L37, # 1-35].

Figure 2.2: Osram Offices, Quickborner, Munich, 1963. A typical layout of a Bürolandschaft (Office Landscape) where the organic arrangement of desks was designed to reflect communication flows rather than hierarchy. Source: [Walter Henn and Henn Architects, <https://www.henn.com/en/project/osram-hauptverwaltung-muenchen> - last accessed 2026/03/11]

Figure 2.3: The degeneration of the organic workplace. (A) The original Action Office, designed by Robert Propst for Herman Miller (1964), intended to provide knowledge workers with flexible, dynamic environments, varied postures, and calibrated visual privacy. (B) A typical Cubicle Farm from the late 20th century. Driven by real estate cost-saving logic, corporate management rigidly standardized Propst's flexible partitions, enclosing workers in tight, orthogonal modules. This

evolution marked the failure of spatial autonomy, generating profound sensory isolation. Source: [<https://k2space.co.uk/knowledge/history-of-office-design> – last accessed 2026/03/11].

Figure 2.4: Diagram illustrating the relationship between architectural parameters (inputs) and human psychophysiological responses (outputs) within the neuroarchitectural framework. Source: [Author]

Figure 2.5: Conceptual model of Attention Restoration Theory (ART). The diagram illustrates the depletion of directed attention during cognitively demanding tasks (fatigue) and its potential recovery through effortless attention associated with soft fascination. Adapted from Kaplan & Kaplan (1989). Source: [CATS-Cambridge-Newsletter, 12th May 2023]

Figure 2.6: Conceptual architectural sketch illustrating the Prospect-Refuge theory. The worker's position balances physical protection from behind (Refuge) with an unobstructed visual field for environmental monitoring (Prospect). Source: [Author]

Figure 2.7: The Inverted-U relationship between visual complexity and aesthetic preference, based on Berlyne's Arousal Theory (1971). The model demonstrates that cognitive well-being and positive hedonic responses are achieved at intermediate levels of environmental complexity, avoiding both sensory deprivation and cognitive overload. Source: [DOI:[10.31234/osf.io/f98kv](https://doi.org/10.31234/osf.io/f98kv)]

Figure 3.1: Synoptic overview of the methodological workflow, from the definition of the independent variables to the qualitative triangulation of EEG and psychometric data. Source: [Author].

Source: [Author].

Figure 3.2: Conceptual matrix of the 2x2 within-subjects factorial design, illustrating the four experimental Mixed Reality scenarios defined by the intersection of the Independent Variables (ID): Visual Openness (VO) and Perceived Complexity (PC). Source: [Author].

Figure 3.3: Dependent Variables (VD) of the study, grouped by measure domain (neurophysiological / self-report). Divided into Frontal Theta (cognitive load), Parietal Alpha (visuospatial processing), FAA (proxemic stress), and self-report. Source: [Author].

Figure 3.4: The static morphological bounding box of “La Nave” (floor G). The structural grid and perimeter boundaries act as an invariant geometric constraint

across all experimental scenarios, ensuring the ecological validity of the simulation. Source: [Author].

Figure 3.5: Example of algorithmic extraction of Visual Openness (VO) using isovist analysis. The coloured polygon represents the 360-degree visible area from a predefined Vantage Point (VP) set at eye level (1.65 m) along the exploration path. Source: [Author].

Figure 3.6: Algorithmic extraction of Perceived Complexity (PC). Left: the 3D perspective rendered with uniform Lambertian surfaces to exclude material interference. Right: the same scene processed via the Canny edge detection algorithm to isolate high-frequency contrast gradients (Edge Density). Source: [Author].

Figure 3.7: Summary of the participant inclusion criteria. The study included 20 master's students in Architecture. Selection required strong right-handedness (Edinburgh Handedness Inventory score of 8 or higher), normal vision and no previous neurological history. Source: [Author].

Figure 3.8: The experimental apparatus employed in the study, comprising the Meta Quest 3 Mixed Reality (MR) headset for virtual spatial simulations, the Emotiv EPOC X wireless Electroencephalography (EEG) headset for real-time neurophysiological data collection and the ZED 2i AI STEREO Camera. Source: [Author]

Figure 3.9: Topographic layout of the 14-channel Emotiv EPOC X headset according to the international 10-20 system. The prefrontal (AF3, AF4) and frontal (F3, F4) clusters are highlighted, as they serve as primary regions of interest for monitoring Frontal Alpha Asymmetry (FAA) and Theta synchronization. Source: [Author].

Figure 4.1: Pavia, Italy - 1:20,000 scale adapted. Source: [Author]

Figure 4.2: The Cravino scientific pole in Pavia. The original masterplan as envisioned by Giancarlo De Carlo. Source: [Giancarlo De Carlo and the faculty of engineering of Pavia, 2012]

Figure 4.3: Current masterplan of the Cravino scientific pole in Pavia. Source: [Author].

Figure 4.4: Current layout of floor G. Source: [Author].

Figure 4.5: Isovist analysis of the existing configuration of floor G. Source: [Author].

Figure 4.6: Edge density analysis of the existing configuration of floor G.

Source: [Author].

Figure 4.7: Function diagram, Floor G, La Nave, Cravino Campus. Source: [Author].

Figure 4.8: Flow diagram, Floor G, La Nave, Cravino Campus. Source: [Author].

Figure 5.1: Scenario generation and validation workflow, from abstract typological selection to MR-EEG experimental execution. Source: [Author].

Figure 5.2: Morphological abacus of the 20 abstract spatial configurations generated for the study. The layouts are categorised into four typological quadrants based on the interaction between PC and VO. The variants highlighted in red (1.1, 2.5, 3.2, 4.3) represent the final scenarios selected for the subsequent MR-EEG experimental phase. Source: [Author].

Figure 5.3: Floor plan of Scenario 1 (Baseline: Low VO/Low PC). The design features a traditional orthogonal layout with full-height partitions, creating isolated cellular offices and ensuring low perceived complexity alongside high visual occlusion. Source. [Author].

Figure 5.4: Visualization of the view seen through the Meta Quest 3 headset for Scenario 1 (Baseline: Low VO/Low PC). Source. [Author].

Figure 5.5: Floor plan of Scenario 2 (High VO/Low PC). The orthogonal grid is maintained, but partitions are lowered to 1.20 meters. This configuration establishes a standard open-plan environment, maximizing visual openness and minimizing geometric complexity. Source. [Author]

Figure 5.6: Visualization of the view seen through the Meta Quest 3 headset for Scenario 2 (High VO/Low PC). Source. [Author].

Figure 5.7: Floor plan of Scenario 3 (Low VO/High PC). A highly fragmented, labyrinthine configuration characterized by organic, non-orthogonal walls extending to full height. This layout severely restricts visual depth while drastically increasing geometric articulation. Source. [Author].

Fig. 5.8: Visualization of the view seen through the Meta Quest 3 headset for Scenario 3 (Low VO/High PC). Source. [Author].

Fig. 5.9: Floor plan of Scenario 4 (High VO/High PC). The irregular, zig-zag geometric footprint of scenario 3 is maintained, but the partitions are uniformly reduced to 1.20 meters. This layout juxtaposes high structural complexity with extensive spatial visibility. Source: [Author].

Fig. 5.10: Visualization of the view seen through the Meta Quest 3 headset for Scenario 4 (High VO/High PC). Source: [Author].

Figure 5.11: Isovist analysis of scenario 1. Source: [Author].

Figure 5.12: Isovist analysis of scenarios 2 and 4. Source: [Author].

Figure 5.13: Isovist analysis of scenario 3. Source: [Author].

Figure 6.1: Bar heights represent the mean scores (N=20). Error bars indicate ± 1 Standard Deviation, illustrating response variance. Source: [Author].

Figure 6.2: Mean score for the environmental assessment (Kaplan & Kaplan framework). Error bars indicate ± 1 Standard Deviation. Source: [Author].

Figure 6.3: Mean score for cognitive load and stress (adapted NASA-TLX). Error bars indicate ± 1 Standard Deviation. Source: [Author].

Figure 6.4: Mean score for overall workplace feasibility. The bar chart illustrates the participants' behavioural intent regarding the suitability of each architectural layout for performing daily work tasks. Error bars indicate ± 1 Standard Deviation. Source: [Author].

Figure 6.5: Raw time-domain EEG traces of participant 07 (P07) during the four experimental scenarios. Note the visible amplitude increase in the frontal channels (especially AF3, F7) in scenario 3 compared to the baseline, which is then resolved in scenario 4. Source: [Author].

Figure 6.6: Raw time-domain EEG traces of participant 07 (P07) focusing on the parieto-occipital channels (P7, P8, O1, O2). Scenario 4 demonstrates the most composed and stable trace, suggesting a reduction in visual effort when visual openness is increased. Source: [Author].

Figure 7.1: Floor plan of proposed layout. Source: [Author].

Figure 7.2: Function diagram of proposed layout. Source: [Author].

Figure 7.3: Flow diagram of proposed layout. Source: [Author].

Figure 7.4: Isovist analysis of proposed layout. Source: [Author].

Figure 7.5: 3D model of proposed layout. Source: [Author].

List of tables

Table 5.1: Isovist analysis of scenario 1. Parameters confirm minimal visual openness and high spatial occlusion.

Table 5.2: Isovist analysis of scenarios 2 and 4. Metrics reflect total visual exposure and the absolute absence of protective proxemic boundaries.

Table 5.3: Isovist analysis of scenario 3. Values indicate excessive spatial fragmentation and continuous interruption of the visual field.

Table 5.4: Edge Density analysis of Scenario 1. Minimum values indicate sensory deprivation and absolute visual flatness.

Table 5.5: Edge Density analysis of Scenario 2. The low edge density reflects an environment poor in stimuli and cognitively inert.

Table 5.6: Edge Density analysis of Scenario 3. Percentage peaks certify excessive fragmentation and a high risk of cognitive overload

Table 5.7: Edge Density analysis of Scenario 4. The 3% mean value confirms the achievement of an optimal perceived complexity to sustain attention.

Table 6.1: Structure and items of the spatial exploration questionnaire.

Table 6.2: Qualitative matrix of frontal activation. Summary of inter-subject visual inspection

Table 7.1: Parametric validation certifies the success of the Evidence-Based Design intervention. The balance between extensive visual perimeter (80.3 m) and the deep Occlusivity (0.88) demonstrates the physical achievement of the optimal cognitive parameters, successfully preventing both sensory deprivation and visual overload.

Table 7.2: Computational analysis confirms the success of the geometric and material strategy. The mean Edge Density of 3% represents the ideal neuroergonomic threshold, introducing sufficient visual complexity to sustain active attention whilst preventing the cognitive overload typical of fragmented environments.

Table 7.3: The reduction of massive structural partitions has allowed for the recovery of useful space, allowing the proposed layout to significantly expand circulation areas and increase the total capacity of the workstations without altering the overall footprint of the building.

List of acronyms

ABW

Activity-Based Working

AR

Augmented Reality

ART

Attention Restoration Theory

CBE

Center for the Built Environment (University of California, Berkeley)

CNS

Central Nervous System

EBD

Evidence-Based Design

EBM

Evidence-Based Medicine

EEG

Electroencephalography

FAA

Frontal Alpha Asymmetry

fMRI

Functional Magnetic Resonance Imaging

HPA (axis)

Hypothalamic-Pituitary-Adrenal (axis)

IEQ

Indoor Environmental Quality

IVR

Immersive Virtual Reality

MoBI

Mobile Brain/Body Imaging

MR

Mixed Reality

PC

Perceived Complexity

POE

Post-Occupancy Evaluation

ROI

Return On Investment

SBS

Sick Building Syndrome

VO

Visual Openness

WHO-HPQ

World Health Organization – Health and Work Performance Questionnaire

Glossary of Key Terms

Activity-Based Working (ABW)

A contemporary workplace strategy characterised by the absence of assigned desks, where employees choose between different micro-environments based on the specific task they need to perform.

Allostatic Load

The cumulative biological degradation of the bodies and brain's systems caused by the prolonged activation of the body's stress response mechanisms, often because of prolonged exposure to sub-standard indoor environmental quality or lack of privacy.

Arousal Theory

A psychological theory developed by D. Berlyne that suggests that the hedonic response of the human brain to visual stimuli, particularly complexity, follows the shape of the inverted 'U' curve.

Bürolandschaft (Office Landscape)

An early organizational design concept from the 1950s that abandoned the traditional orthogonal desk grids in favour of an organic design that featured a barrier-free layout.

Cognitive cost

The hidden metabolic and psychological load that the body is subjected to as a result of the lack of support from the working environment, leading to fatigue, stress, and reduced cognitive efficiency.

Cognitive load

The total amount of information that is processed and stored by the working memory. In open-plan spaces, this is artificially maximized as the brain is forced to filter out distracting auditory and visual stimuli.

Cost-saving

In the context of real estate and facilities management, the primary economic justification for densifying the workspace and reducing the amount of floor area allocated to each employee.

Deep work

A condition of sustained, distraction-free concentration that is essential to complex cognitive functions, problem-solving, and high-value knowledge production.

Directed Attention Fatigue

A process of cumulative depletion of the voluntary, cognitively demanding attentional system due to the sustained effort of focusing on a goal while suppressing peripheral distractions.

Edge Density

A computer-based geometric metric used to objectively measure the visual complexity of a scene, which is defined as the amount and concentration of high-contrast transitions (edges) found in the visual field.

Evidence-Based Design (EBD)

A design methodology that uses the best empirical and scientific evidence to inform critical design decisions, moving beyond aesthetic intuition.

Frontal Alpha Asymmetry (FAA)

An EEG-based biomarker that is defined as the difference in power between the left and right prefrontal cortex alpha wave activity, which is used to inform approach/avoidance motivation and spatial stress.

Gold Standard

In scientific research, the most reliable, accurate, and universally accepted methodological procedure or diagnostic test is currently available for a particular condition or research question.

Hot-Desking

An office design system that uses desks as workstations that are used by different

people at different times on an ad hoc basis, thereby eliminating the traditional personal workstation and territoriality.

Isovist

In spatial analysis, the aggregate area or volume of space that is perceivable from a particular vantage point in an environment is used to obtain a mathematical description of Visual Openness.

Immersive Virtual Reality (IVR)

A highly advanced computer-generated simulation that replaces the user's physical surroundings completely with a digital three-dimensional replica. Immersive Virtual Reality (IVR) technology, provided in the form of a head-mounted display (HMD), provides users with an enclosed and stereoscopic field of view that is both ecologically valid and allows for stringent control over extraneous variables in neuroarchitectural experiments.

Knowledge workers

Knowledge-based employees, whose main capital consists of their knowledge and whose work involves intricate information processing, problem-solving, and creative cognition, display high dependency on their ability to concentrate.

Mobile Brain/Body Imaging (MoBI)

An experimental research approach that makes use of neuroimaging technologies, like mobile EEG, in combination with motion capture and virtual reality, so that brain activity in moving human subjects can be studied in an ecologically valid setting.

Mixed Reality (MR)

A highly sophisticated technology that enables people to interact in real time in virtual architectural scenarios and in the physical world.

Neuroergonomics

An interdisciplinary science that makes use of the discoveries of neuroscience in the fields of human factors and ergonomics, in an attempt to develop workspaces and work that are in harmony with the human brain.

Neuroimaging

The application of multiple sophisticated technologies (e.g., EEG, fMRI) in the direct or indirect observation of nervous system structure, function, and pharmacology.

Neutral background

An outdated concept in architecture that regarded the environment as passive, that is, as not actively influencing human physiological and/or psychological health.

Optimal zone

According to Arousal Theory, the peak in the inverted-U relationship indicates an optimum level of stimulation in the environment, for example, complexity, that is favorable for cognitive well-being and aesthetic preference.

Perceived Complexity

The subjective human experience of structural articulation, richness, and variety within a spatial configuration or visual field.

Post-Occupancy Evaluation (POE)

A standard facility management process used to evaluate building performance after construction and occupation, based on subjective occupant satisfaction surveys.

Presenteeism

An organizational state wherein people are physically present at their workstations but are functioning with a significantly reduced cognitive ability due to mental exhaustion, distraction, or environmental stress.

Prospect-Refuge theory

An evolutionary psychology model that asserts humans are naturally drawn to environments with an unobstructed field of view (prospect) and a secure enclosed space (refuge).

Return on Investment (ROI)

A financial model used to evaluate the efficacy or profitability of an investment; it is often incorrectly calculated by focusing on densities rather than the cognitive productivity of employees.

Self-report bias

A methodological flaw in survey research wherein respondents misrepresent their feelings, behaviours, or sources of discomfort due to a lack of introspective accuracy.

Sick Building Syndrome (SBS)

A medical condition in which building occupants report acute health and comfort responses that seem to be associated with time spent in each building, exacerbated by poor environmental quality and spatial stress.

Soft fascination

A concept from Attention Restoration Theory referring to a state of effortless attention that is automatically generated in response to restorative stimuli, allowing the directed attention system in the brain to recover from fatigue.

Theta/Beta ratio

A neurophysiological measure obtained from EEG that reflects a balance between slow (theta) and fast (beta) brain activity; high levels are indicative of high cognitive demands, fatigue, and inefficient attentional processing.

Visual Openness

The level of visual access and expansiveness in an architectural layout that affects an occupant's perception of environmental monitoring (Prospect) or exposure.

Withdrawal

A motivational state or behavioral drive in neuropsychology referring to an occupant's desire to escape a negative or stressful stimulus; in terms of spatial stress, an occupant desires to escape a stressful architectural environment.

Appendix A - PARTICIPANT INFORMATION SHEET



Study Title: Effects of architectural spatial Configuration on cognitive load and spatial perception in Virtual Environments

Principal Investigator: Sofia Casile, master's Candidate

Academic Supervisor: Yan Chao, Marco Morandotti

Department/Institution: Tongji University, Università di Pavia

Contact Email: sofia.casile01@universitadipavia.it

1. Invitation and Purpose of the Study

You are being invited to take part in a research study. Before you decide to participate, you must understand why the research is being done and what it will involve. The purpose of this study is to investigate how different architectural layouts (specifically varying in visual openness and spatial geometry) impact human cognitive load and spatial perception. To measure this, we utilize Immersive Virtual Reality (VR) combined with Electroencephalography (EEG).

2. What will happen if I take part?

If you agree to participate, the experimental session will last approximately [Insert Time, e.g., 45-60] minutes. You will be asked to:

- Wear a non-invasive EEG headset that records surface brain activity.
- Wear a VR Head-Mounted Display to explore 4 different virtual office layouts.
- Complete a digital questionnaire after navigating each scenario to evaluate your spatial perception and mental workload.

3. Important Medical Disclaimer regarding EEG

Please note that the EEG equipment used in this study is utilized strictly for academic research purposes to measure general cognitive load. **It is not a medical device.** The data collected will not be used for medical diagnosis, nor can the researcher provide any health-related feedback or neurological assessment based on your brainwave activity.

4. Potential Risks and Discomforts

The physical risks are minimal, but you should be aware of the following:

- **Cybersickness:** Exposure to VR can sometimes cause mild nausea, dizziness, or visual fatigue.

- **Spatial Disorientation:** Some architectural layouts are deliberately complex and may cause temporary frustration or spatial confusion.
- **Equipment Discomfort:** The VR and EEG headsets may cause slight pressure on the head.
If you experience any physical or psychological discomfort, you can stop the experiment immediately by removing the headset or informing the researcher.

5. Do I have to take part?

No. Participation is entirely voluntary. You can withdraw from the study at any time during the experimental session without giving a reason and without any negative consequences.

6. Data Privacy and Confidentiality

Your data will be processed in strict compliance with current data protection regulations.

- **Pseudonymization:** Your name will not be linked to your EEG data or questionnaire responses. You will be assigned a numerical Participant ID (e.g., P01).
- **Data Storage:** The master list linking your real name to your Participant ID will be stored on a secure, password-protected offline drive, accessible only to the primary researcher and the academic supervisor.
- **Data Usage:** The pseudonymized data will be analyzed for a Master's thesis and potential academic publications. Once the data is aggregated and analyzed, it will not be possible to withdraw your individual dataset.

INFORMED CONSENT FORM

Participant ID: _____ *(To be filled by the researcher)*

Please read the following statements carefully and initial each box to indicate your agreement, then sign at the bottom of the page.

- I confirm that I have read and understood the Participant Information Sheet for the above study. I have had the opportunity to consider the information, ask questions, and have had these answered satisfactorily.
- I understand that my participation is voluntary and that I am free to withdraw at any time during the experiment, without giving any reason and without any negative consequences.
- I understand that the experiment involves wearing a Virtual Reality (VR) headset and an Electroencephalography (EEG) device, which may cause mild fatigue, dizziness, or cybersickness.
- I acknowledge that the EEG recording is for research purposes only regarding cognitive load and is not a medical diagnostic procedure.

- I understand that my personal data will be pseudonymized. My name will not appear in any publications or thesis outcomes, and the data will be securely stored and accessed only by the research team.
- I agree to allow the data collected during this study to be used for academic purposes, including the final thesis, academic presentations, and future scientific publications in an aggregated or anonymized format.
- I confirm that I am over 18 years of age.

Declaration of Consent

By signing below, I voluntarily agree to participate in this research study.

Participant's

Printed

Name:

Participant's

Signature: _____

Date:

Researcher's

Printed

Name:

Researcher's

Signature: _____

Date: _____

Appendix B - PYTHON SCRIPT FOR EDGE DENSITY CALCULATION

```
import cv2
import numpy as np

def calculate_edge_density(image_path, threshold1=30, threshold2=100):
    """
    Calculates the Edge Density of a given grayscale architectural perspective
    using the Canny Edge Detection algorithm.
    """
    # 1. Load the image from the specified path
    img = cv2.imread(image_path)

    if img is None:
        raise ValueError("Image not found. Please check the file path.")

    # 2. Convert the image to grayscale to isolate luminance
    gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)

    # 3. Apply the Canny Edge Detection algorithm
    # Thresholds (30, 100) are set to capture architectural geometry
    # while ignoring minor rendering noise on Lambertian surfaces.
    edges = cv2.Canny(gray, threshold1, threshold2)

    # 4. Calculate the total number of pixels in the image
    total_pixels = edges.shape[0] * edges.shape[1]

    # 5. Count the number of edge pixels (white pixels, value > 0)
    edge_pixels = np.count_nonzero(edges)

    # 6. Compute the Edge Density percentage
    edge_density = (edge_pixels / total_pixels) * 100

    # 7. Print the analytical results
    print(f'Analysis for: {image_path}')
    print(f'Total Pixels: {total_pixels}')
    print(f'Edge Pixels: {edge_pixels}')
    print(f'Edge Density: {edge_density:.4f}%')
    print("-" * 30)
```

```
return edges, edge_density
```

```
# Example Execution
```

```
# result_img, density = calculate_edge_density('scenario1_punto1_ED.jpg')
```