

# BEYOND PHYSICAL BOUNDARIES: THE CONCEPT AND CHARACTERISTICS OF COGNITIVE SPATIAL SEGMENTATION

Kyunghyun CHO<sup>1</sup>, Jisoo KANG<sup>1</sup> and Seung Hyun CHA<sup>1</sup>

<sup>1</sup>Korea Advanced Institute of Science and Technology, South Korea

## ABSTRACT

Cognitive Spatial Segmentation refers to the cognitive process by which individuals perceive a physically continuous space as multiple distinct zones or rooms, guided by spatial, sensory, and contextual cues. While this mechanism is fundamental to human spatial cognition, its role in design has been largely overlooked, even as contemporary architectural environments increasingly dissolve physical boundaries in favor of multifunctionality. As a result, many spatial settings suffer from inefficiency, disorientation, and elevated cognitive load for users. At the same time, spatial environments are being radically reshaped by advanced ICT technologies, including virtual reality (VR) and spatial computing, which diminish the role of physical objects as primary boundaries. Without a clear theoretical foundation, these rapid shifts risk producing fragmented and less usable environments. To address this urgent gap, this study defines the terminology and conceptual framework of Cognitive Spatial Segmentation and proposes a classification system for spatial design elements based on their core characteristics. By establishing this theoretical foundation, the research seeks to advance academic discourse, facilitate its integration into spatial design practice, and provide practical guidelines for both physical and virtual reality space design.

*Keywords: Cognitive Spatial Segmentation, Spatial Perception, Conceptual Partitioning, Perceptual Boundaries, Cognitive Territoriality*

## 1 INTRODUCTION

Contemporary architectural design has increasingly embraced the concept of integrated space, where functional versatility, adaptability, and efficiency are prioritized over rigid physical boundaries [4, 10, 17]. This trend is visible in multiple domains: in residential contexts, open-plan kitchens merge cooking, dining, and living functions into a single multipurpose environment [7, 28]; in workplaces, open-plan offices seek to promote collaboration and reduce costs; and in cultural and educational facilities, flexible layouts are employed to maximize shared use [22]. These transformations reflect not only economic pressures such as limited space and cost-efficiency [27] but also evolving cultural values and social trends favoring openness, interaction, and adaptability.

Yet, the increasing dissolution of physical partitions often creates substantial challenges for end users. Without clear spatial boundaries, individuals are exposed to competing demands within a single environment, leading to distraction, inefficiency, and cognitive overload. For instance, research has shown that employees in open-plan offices experience more frequent distractions and reduced focus compared to those in cellular offices [14, 32]. During the COVID-19 pandemic, remote workers likewise reported difficulty separating professional duties from household routines, resulting in decreased productivity and heightened fatigue [18, 33]. Similarly, students in flexible learning spaces often struggle to sustain concentration amid constant spatial reconfigurations [35]. These cases reveal a central paradox: although integrated spaces promise efficiency and adaptability, in practice they frequently place the burden of mental organization on users, undermining the very goals they are designed to achieve.

To address this paradox and clarify how users cognitively organize integrated environments, the concept of Cognitive Spatial Segmentation becomes critical. Drawing on selective attention theory, flow state theory [8, 9], and spatial presence theory [34], Cognitive Spatial Segmentation refers to the cognitive process by which individuals perceive and construct distinct functional zones within a

continuous environment. By understanding how users mentally partition space, architects and designers can better anticipate user behavior, reduce unintended distractions, and enhance both efficiency and experiential quality in integrated settings. Moreover, individuals without professional design training can apply this concept through simple strategies, such as arranging furniture or employing visual markers, to cognitively structure their own environments.

The significance of such Cognitive Spatial Segmentation becomes even more critical for the spaces of the near future. Rapid advances in virtual reality (VR) technology are introducing entirely new spatial types that are free from physical constraints. In VR environments, there are no material boundaries to determine where one space ends and another begins, allowing multiple environments to coexist or overlap within a single immersive setting. However, this very freedom also poses the challenge of establishing clear principles for distinguishing and organizing spaces to prevent perceptual confusion and loss of orientation. To ensure the usability and design coherence of VR environments, spatial divisions must therefore be grounded in users' perceptual and cognitive mechanisms. Understanding how users cognitively segment VR space provides the foundation for designing environments that remain both legible and experientially consistent, even in the absence of physical form.

Despite its relevance, Cognitive Spatial Segmentation remains underdeveloped in architectural discourse. There is no clear definition or shared terminology, and related concepts have been inconsistently described across psychology, environmental studies, and cognitive science: for example, subjective partition of space [11], conceptual boundaries [15], cognitive territoriality [16], or spatial subdivision [31]. The absence of a unified framework has hindered the accumulation of knowledge and left the concept marginal in architectural design practice, where communication gaps between designers and users persist [1, 5]. Therefore, this study seeks to define the terminology and conceptual framework of Cognitive Spatial Segmentation and to propose a theoretical classification model for spatial design elements. Establishing this foundation will not only enrich academic discourse but also provide architects, designers, and users with practical guidelines for creating environments, both physical and virtual reality, that balance integration with cognitive clarity.

## 2 BACKGROUNDS

Humans inherently segment and categorize space along cognitive dimensions, a phenomenon that has been widely examined across diverse academic disciplines. Humans cognitively segment space by conceptualizing territory based on points and paths [11], aligning with the seminal theory that people perceive cities as mental images composed of nodes, edges, paths, districts, and landmarks [21]. Importantly, it was highlighted in [21] that edges serve as perceived boundaries and districts as discrete zones, underscoring how individuals create boundaries to define spatial territories and categorize them into distinct regions. Similarly, a study suggested that spatial perception is structured schematically, prioritizing key elements such as paths and points over precise physical representations [30]. It was further emphasized in [6] that spatial segmentation often arises from perceptual discontinuities; even subtle changes in height, form, or texture can divide an otherwise continuous environment. Expanding this perspective, [23] demonstrated that individuals perceive space across four psychological scales—figural, vista, environmental, and geographic—rather than as a continuous whole, with each scale defined by recognizability and accessibility. More recently, [24] provided neuroscientific evidence that humans mentally segment complex environments into subspaces, schematizing spatial information into cognitively manageable units.

From an architectural perspective, prior studies on Cognitive Spatial Segmentation can be organized into three dimensions: physical, normative, and interpretive.

*Physical Spatial Segmentation* refers to the complete division of space by physical objects. Traditional architectural theory defines space through structural elements such as ceilings, walls, and floors, which establish boundaries [6]. A single space maintains physical and visual continuity until such continuity is disrupted. Disruption may result from changes in form—e.g., variations in floor height, the presence or absence of a ceiling, or shifts in vertical scale—as well as alterations in color, texture, or material. Notably, visual disruption takes precedence over physical separation; for instance, a space is perceived as segmented when an object rises to eye level and obstructs sight [6].

*Normative Spatial Segmentation* occurs when space is divided based on sociocultural norms and customary rules formed by community consensus. Examples include gender-segregated restrooms, quiet zones in libraries, and no-kids areas in cafés. [15] argued that space serves as a framework for cultural values and social structures beyond its physical form, demonstrating that residential layouts differ across

cultures due to variations in gender roles, privacy, and household norms. Moreover, it was found that linguistic differences influence spatial cognition [3], while [26] reinforced this view by emphasizing how language, as part of culture, shapes cognitive segmentation. Residential environments also illustrate this phenomenon. The widespread adoption of open-plan kitchens in suburban housing has merged previously discrete rooms such as kitchen, dining, and living spaces into one integrated environment. Yet, cultural practices still maintain subtle subdivisions through breakfast nooks, dining tables, or kitchen bars, suggesting that normative segmentation can be flexible and subject to evolving social trends.

*Interpretive Spatial Segmentation* arises when individuals cognitively segment a space by interpreting its purpose and function, assigning meaning based on formal characteristics, spatial experiences, and contextual cues. For example, a child may define a personal play area with a carpet in a Montessori school playground [13]. It was examined in [31] that humans distinguish spaces through Boundary Line Types (BLTs), suggesting that segmentation arises from interpreting spatial boundaries informed by prior knowledge and experience. Similarly, [2] validated that children segment home environments and assign personal meanings to them, while [12] observed that children perceive corners as psychologically calming. This interpretive dimension also applies in architectural practice: restaurants often arrange furniture clusters, such as open tables, booths, 4-tops, 2-tops, or bar seating, to segment one continuous dining hall into socially distinct zones, allowing users to interpret and occupy territories according to group size, intimacy, or dining style. Likewise, [19] introduced the term cognitive spatial concept, emphasizing that spatial perception is shaped by users' cognitive structures rather than strictly following architectural order. Similarly, [16] proposed cognitive territoriality, describing how users recognize territories not through walls or ceilings but by perceiving clusters of objects with similar forms that contrast with their surroundings.

Although previous studies have examined spatial cognition and segmentation from multiple perspectives, few have established segmentation behavior as an independent design concept grounded in individual cognitive mechanisms. In particular, research remains scarce on how users cognitively segment a single continuous space in response to disruptions in formal, sensory, and contextual factors. Therefore, this study formally introduces the concept of Cognitive Spatial Segmentation and proposes a theoretical classification system to interpret it as a design element.

### **3 COGNITIVE SPATIAL SEGMENTATION: THE DEFINITION AND CHARACTERISTICS**

#### **3.1 Prerequisites and Scope of the Definition**

Prior to defining the terminology and concepts of Cognitive Spatial Segmentation, it is essential to establish the prerequisites and scope to ensure clarity in their meaning and application. First of all, the spatial scale considered in this study is limited to human-scale space, widely dealt with in the field of architectural design, rather than macro-scale regions, such as urban or continental areas. This restriction is intended to prevent confusion with similar terms used in other disciplines, where spatial segmentation may have entirely different meanings. By defining Cognitive Spatial Segmentation within this specific scope, the concept is framed as one that deals with direct and practical phenomena related to how individuals interact with and experience space in their everyday environments. It emphasizes the importance of studying segmentation at a scale that directly affects human perception and behavior, rather than at an abstract or vastly different spatial level.

Second, humans rely on multiple sensory modalities when perceiving space, but vision plays the most dominant role in spatial recognition. This has been empirically validated in various studies [25, 29] and is widely recognized as a foundational principle in architecture and spatial design [19]. The significance of visual perception in spatial segmentation is further highlighted in [6], who frequently identifies it as a primary criterion for how spaces are cognitively divided. While other sensory inputs, such as auditory and haptic feedback, contribute to spatial perception, they function in a supplementary manner, reinforcing the primarily visual nature of spatial segmentation. Understanding this hierarchy of sensory influence is crucial in defining Cognitive Spatial Segmentation as a process that is largely driven by visual cues rather than purely physical obstructions.

Third, Cognitive Spatial Segmentation refers to the phenomenon in which individuals perceive and utilize space within a single spatial unit by mentally dividing it into distinct areas. In this context, a single space is defined as an environment where no physical barriers exist between two locations,

allowing users to move freely without the need for additional installations such as doors, stairs, or ramps. This definition aligns with architectural theory, where such a unit represents the smallest recognized spatial entity. Unlike traditional architectural divisions, which are based on fixed structural elements, Cognitive Spatial Segmentation introduces a new perspective by emphasizing how users temporarily and subjectively subdivide a continuous space into smaller functional or perceptual zones. This segmentation is not dictated by predefined architectural boundaries but rather by how individuals interpret and utilize spatial characteristics.

Finally, the concept of Cognitive Spatial Segmentation is limited to phenomena experienced by end users as subjective spatial agents, rather than those imposed through intentional architectural design. It does not focus on planned design interventions by architects or spatial designers but instead explores the ways in which users independently and dynamically perceive, organize, and segment space. This perspective underscores the fluid and user-dependent nature of spatial experience, where segmentation arises naturally through interaction with environmental cues rather than being a rigidly imposed structure. By shifting the focus to the end user's cognitive process, this approach highlights the adaptability and personal agency involved in spatial perception within an integrated and universally accessible environment. Based on the prerequisites described above, the scope of the concept is summarized in Table 1.

Table 1. Semantic Scope for Definition of the Terminology and the Concept

Contents	Scope
Target Space	Physically Continuous Human-scale Architectural Space
Major Sensorial Modality	Visual Perception, complemented by other sensory cues
Subject	End User Actually Experiencing and interacting with the Space
Influencing Ways of Defining Space	<ul style="list-style-type: none"> <li>- <b>Creating Cognitive Boundaries:</b> through Physical, Visual, or Symbolic Cues</li> <li>- <b>Structuring Functional Utilization:</b> guiding how subzones are used</li> <li>- <b>Normative Rules:</b> Social and Cultural Conventions shaping Spatial Definition</li> <li>- <b>Interpretive Meaning-Making:</b> Users Assigning Purposes and Values to Areas</li> </ul>

### 3.2 Conceptual and Terminological Definition of the Concept

The semantic definition of Cognitive Spatial Segmentation, grounded in the theoretical background and prerequisites, is as follows:

*Cognitive Spatial Segmentation* refers to the ability or act of an individual user to mentally segment a physically and visually continuous space into cognitive subspaces. This segmentation occurs at transition points or boundaries formed by disruptions in formal or contextual consistency.

In this context, consistency is a subordinate concept to the previously mentioned visual and physical continuity. It refers to the degree to which spatial characteristics or contextual properties within a single space are maintained. A disruption of consistency serves as a mechanism that creates cognitive boundaries or transition points at a location of an object within that space. The concept is illustrated in Figure 1.

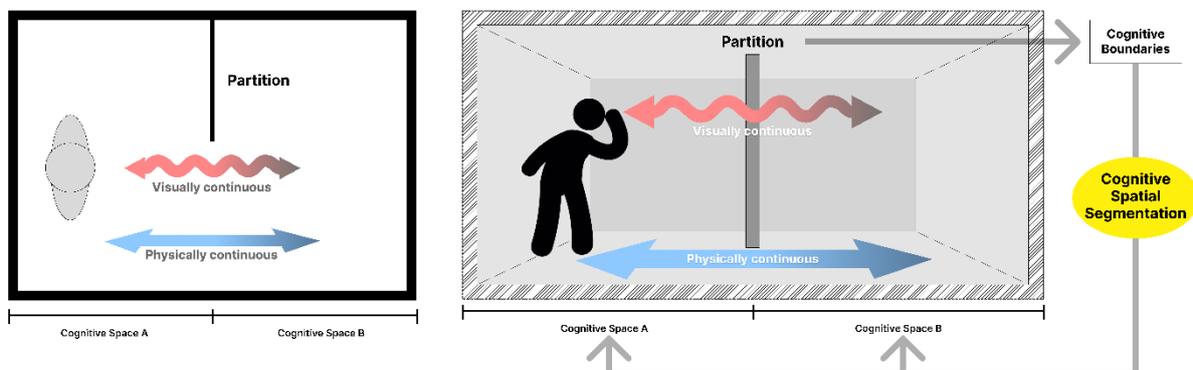


Figure 1. Conceptual Plan (left) and Perspective (Right) of Cognitive Spatial Segmentation: Visualizing how design elements Influence User's perceived segmentation of Space

Based on the semantic definition of the concept, the terminology used in this study is determined as follows. The term *cognitive* is chosen to reflect the perceptual and interpretive process through which individuals sense and assign meaning to space. This highlights the active role of human cognition in recognizing and structuring spatial environments. The word *space* refers to the fundamental unit of architecture, defined neutrally as a bounded void that provides an area available for use. By adopting this definition, the study ensures that the concept remains broadly applicable without being restricted to specific architectural styles or functions. Finally, the term *segmentation* is selected for its ability to express both the process and the outcome of division in a perceptual and flexible manner. Unlike terms that imply rigid or permanent separations, segmentation captures the dynamic and subjective nature of spatial division as experienced by users. Given these considerations, this study proposes to unify the concept under the term *Cognitive Spatial Segmentation*, which effectively encapsulates the core idea of how individuals cognitively divide and structure space within an environment.

### 3.3 Characteristics of the Concept and a Theoretical Model of Classification

Building upon the conceptual definition presented above, Cognitive Spatial Segmentation can be further understood through the underlying mechanism that governs how users mentally divide continuous space. This mechanism is grounded in the principle of consistency, which determines the degree to which spatial characteristics remain coherent across an environment. When such consistency is disrupted, users perceive cognitive boundaries and segment the space accordingly. The principle of consistency, therefore, serves as the core criterion of Cognitive Spatial Segmentation and can be categorized into three types: *formal consistency*, *sensorial consistency*, and *contextual consistency*.

*Formal Consistency* refers to the uniformity of structural components such as ceilings, walls, pillars, and floors, along with attributes like height, area, proportion, and scale. Segmentation occurs when these elements vary within a space and disrupt formal coherence. Examples include changes in wall direction, ceiling or floor height, or the shape and area of the space.

*Sensorial Consistency* concerns the sustained uniformity of aesthetic qualities perceived through the human body's sensory modalities, including auditory, olfactory, and tactile perception. These qualities include hue, texture, materiality, brightness, temperature, and acoustics. A disruption in sensorial consistency arises when discrepancies in these sensory elements occur within the same space, creating a perceptual boundary that cognitively segments the space.

*Contextual consistency* refers to the extent to which the character, meaning, or function cognitively assigned to a space by the user remains stable. This consistency is informed by all spatial components, including furniture, equipment, structural form, and sensory elements. A disruption of contextual consistency occurs when changes in these elements alter the meaning or function associated with specific parts of the space. For instance, the coexistence of different types of furniture, variations in spatial form, or shifts in material properties and textures may produce contextual boundaries. As a result, the user cognitively segments a single space into multiple distinct areas.

At the moment or the point at which at least one among the three consistencies is disrupted, space is cognitively segmented in the user's mind, and the following is a theoretical classification model for applications of the concept on spatial design. Each characteristic factor has a role in a category of the classification model, and description and classification of spatial design elements are summarized in Table 2.

Table 2. A Theoretical Model of Classification for Spatial Design Elements

Categories	Description	Spatial Design Elements	Disruption Mechanism
Formal Consistency	A constant property of structural or attribute elements for the entire space	Ceiling, Wall, Pillar, Floor, Opening / Area, Height, Proportion, Ratio, Size, Scale	<ul style="list-style-type: none"> <li>– Variation of Direction</li> <li>– Cognitive boundaries in user's mind due to partial variation of area/height/proportion/scale/etc.</li> <li>– Cognitive boundaries in user's mind due to partial variation of hue/texture/materiality/temperature/brightness/acoustics type/auditory volume</li> </ul>
Sensorial Consistency	A constant property of sensorial elements the users can perceive	Hue, Texture, Materiality, Temperature, Acoustics, Brightness	

Contextual Consistency	A constant property of spatial meaning, characteristics, function imposed from certain form, furniture, time, facilities	Furniture, Facilities, Certain Spatial Form, Certain Materiality, Time of Use	– Inducing variation in user’s semantic spatial cognition led by furniture, layout, facilities, formal features, certain material, time of use
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## 4 DISCUSSIONS

The concept of Cognitive Spatial Segmentation proposed in this study provides a theoretical framework for explaining how humans mentally partition continuous space. Previous studies have described this phenomenon through various terms, including subjective spatial partitioning [11, 21] and conceptual or cognitive boundaries that reflect perceptual and cultural conventions [15, 16]. Other research has emphasized that spatial cognition is organized schematically rather than physically, and that perceptual interpretation plays a key role in defining spatial boundaries [30, 31]. Despite these contributions, a consistent definition integrating these viewpoints has been lacking. By clearly defining the terminology and semantic scope of Cognitive Spatial Segmentation, this study organizes these dispersed notions into a coherent conceptual structure that links perceptual, formal, and contextual dimensions of spatial cognition.

Building on this conceptual consolidation, the following discussion illustrates its design relevance in contemporary open and multifunctional environments. The increasing prevalence of open and multifunctional environments underscores the need for design principles that preserve cognitive order without relying on physical partitions. Studies on open plan offices reveal that removing physical boundaries can lead to distractions and reduced focus [4, 17], indicating that perceptual segmentation becomes essential to maintain functional clarity. The three consistencies proposed in this study, namely formal, sensorial, and contextual, offer a framework for achieving such cognitive clarity. Prior research demonstrated that spatial perception relies on multisensory integration [29] and that controlling environmental distractions enhances cognitive performance [32]. These findings imply that maintaining perceptual coherence across sensory modalities contributes to both comfort and productivity.

While Cognitive Spatial Segmentation has been defined conceptually, its future development lies in empirical validation and computational modeling. Humans perceive environments across multiple spatial scales, from figural to environmental, reflecting the hierarchical nature of spatial cognition [23]. Neuroscientific evidence further indicates that the brain encodes complex environments as segmented subspaces [24], lending biological support to the framework. Such findings imply that cognitive segmentation can be measured through behavioral and perceptual data such as gaze, movement, or attention patterns. Integrating these empirical approaches could enable the computational representation of cognitive boundaries and establish measurable criteria for cognitive clarity in architectural evaluation. The systematic classification of Cognitive Spatial Segmentation into formal, sensorial, and contextual consistencies provides a structured analytical lens for understanding spatial cognition within VR environments. In VR, where the absence of physical boundaries shifts the burden of spatial legibility onto perceptual and cognitive processes, each consistency plays a distinct yet complementary role. Formal consistency supports the maintenance of geometric order and proportional balance, which are critical for orientation and depth perception in immersive spaces. Sensorial consistency, as supported by prior VR research [25], stabilizes emotional and perceptual responses by minimizing disruptive variations in visual, auditory, or haptic cues that could fragment the user’s sense of continuity. Contextual consistency governs the semantic and functional coherence of the environment, allowing users to anticipate spatial transitions and interpret meaning across VR scenes. Together, these three consistencies offer a cognitive framework for analyzing how VR environments can sustain presence and usability without relying on physical materiality. Moreover, as mixed and adaptive spatial systems evolve, this framework can inform both the design and the empirical evaluation of immersive spaces, establishing cognitive segmentation as a measurable parameter for VR spatial quality and experiential coherence.

## 5 CONCLUSION

This study introduced Cognitive Spatial Segmentation as a user-driven process through which individuals mentally subdivide a physically and visually continuous environment into distinct cognitive subspaces. By establishing a theoretical classification model grounded in formal, sensorial, and contextual consistencies, it provides a unified framework for understanding and designing integrated

spaces. This framework offers designers a conceptual basis for enhancing perceptual clarity and user experience in both physical and VR environments.

The study acknowledges certain limitations, particularly its primary emphasis on visual perception, while auditory, tactile, and olfactory cues also play important roles in spatial cognition. Future research should empirically validate the proposed framework and explore its application through computational modeling and behavioral analysis across disciplines such as architecture, cognitive science, and environmental psychology. By formalizing the terminology and conceptual structure of spatial segmentation, this study contributes to consolidating previously fragmented perspectives and establishes a foundation for data-driven evaluation and intelligent spatial design.

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