Spatial Computing: Key Concepts, Implications, and Research Agenda

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Spatial computing has recently emerged as a promising concept in business, driven by technological advancements and key industry players. In 2023, Apple introduced the term spatial computing alongside the launch of the Apple Vision Pro headset, marking a significant shift in how this technology is perceived and applied across industries. However, while concepts such as Extended Reality or xReality (XR), Augmented Reality (AR), Virtual Reality (VR), and the Metaverse are well-established in both management practice and academic literature, research on spatial computing remains sparse, particularly in a business context. The current research (work-in-progress) addresses this gap by (1) delineating spatial computing from related concepts, and (2) developing a conceptual framework that identifies spatial computing core elements, outcomes, and strategies.

1 Introduction

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2 Literature Review

2.1 Origins of the Term "Spatial Computing"

The word "spatial" comes from the Latin term *spatium*, meaning "space" or "room." It refers to the concept of physical or measurable space, often in relation to dimensions or positioning. The word "computing" comes from the Latin verb *computare*, which is a combination of *com-* (together) and *putare* (to reckon or think). *Computare* means "to calculate" or "to count together," emphasizing the act of processing or calculating data, which is the core of modern computing. In the context of spatial computing, the term signifies the processing and interaction with data related to physical space or environments.

The term spatial computing has been used since the 1980s, primarily associated with geographic information systems and the storage of geospatial data in databases. By 2003, the scope of spatial computing began to shift, particularly with academic work emerging from institutions like MIT. A crucial moment came with the development of systems that linked real-world data with sensor technologies (not limited to XR). These early systems aimed to better understand and

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interact with the physical environment through data processing, but the focus remained largely on sensing technologies rather than immersive experiences.

Over the last years, scholars — mostly from the HCI discipline — have combined sensing technologies with AR and VR systems, and by doing so, slowly shifted the link between "traditional spatial computing" and "XR".

2.2 Augmented and Virtual Reality

Since spatial computing is often closely linked with AR and VR, it is essential to briefly clarify their definitions. Whereas AR integrates digital information with the physical environment, VR immerses users in a completely virtual world. In the case of AR, experiences are categorized based on the level of local presence, which refers to how convincingly virtual content is perceived as part of the user's immediate physical environment. On the other hand, VR experience can be qualified by the level of telepresence (syn: spatial presence, often simply "presence"), i.e., the extent to which users feel that they are in a distant environment, or "being there." We use XR as an umbrella for both AR and VR.

2.3 Metaverse

Since both spatial computing and the metaverse are frequently discussed (inconsistently) in relation to AR and VR, we first systematically identified and categorized existing definitions of the metaverse. Like spatial computing, the metaverse is often framed as a visionary concept. In the following, we briefly present these conceptualizations.

2.3.1 Metaverse as a Closed Industrial Space. A prominent manifestation of the metaverse, especially in business contexts, is the metaverse as a closed, secured, and restricted industrial space. Such an industrial metaverse has been conceptualized as a closed virtual environment where firms can simulate and optimize industrial processes, together with customers and suppliers who can be at different physical locations. A key building block of such a system are digital twins, which we define as real-time, virtual representations of a physical asset (e.g., a machine), a process (e.g., a production process), or a system, thereby allowing the simulation, testing, and direct manipulation of the digital twin's physical counterparts.

2.3.2 Metaverse as a Synonym for VR. One common interpretation equates the metaverse with social VR applications or, in some cases, even single-user VR experiences. However, with the exception of the latter, the emphasis of this metaverse conceptualization is on social interactions and/or the exploration of virtual spaces, typically without commercial components such as the presence of brands, stores, advertising, or NFTs. In most cases, the main purpose of these VR apps is to provide users with a meeting space that can be configured to be more functional (e.g., typical office environment) or more relaxing (e.g., at a beachfront or mountain cabin).

2.3.3 Metaverse as a Colony. Contrary to the previous perspective, metaverse as a colony conceptualizes the metaverse as a replication of the real world, typically with similar economic structures and social processes. These spaces function like colonies: semi-autonomous environments where creators can build and develop their own worlds, engage users, and take part in virtual economic transactions, all within the boundaries of the platform's overarching policies. A substantial amount of academic metaverse research subscribes to this perspective, in which the authors equate platforms such as Decentraland, Sandbox, Minecraft, Fortnite, or Roblox with the metaverse. However, since many of these platforms are accessed through devices with two-dimensional screens such as smartphones or tablets instead of 3D-capable glasses, the metaverse-as-a-colony view often falls short of the ideal of the metaverse as a highly immersive, 3D environment supported by XR technologies.

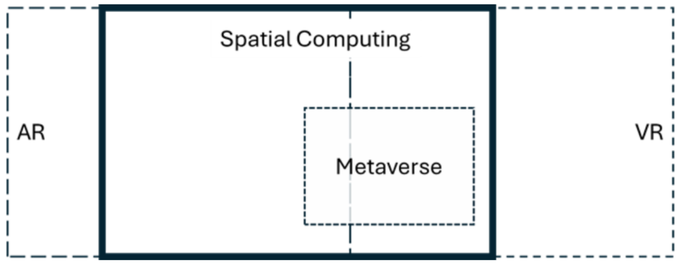

Fig. 1. Delineation of spatial computing (conceptual illustration).

2.3.4 Metaverse as a Vision of a Social and Democratic 3D Internet. Rather than reflecting an existing manifestation of the metaverse, this conceptualization envisions a social, democratic, and highly immersive 3D Internet. Instead of being controlled by single entities or powerful corporations, this future metaverse relies on shared governance through blockchain technology. This vision closely resembles the future metaverse described in Neil Stephenson's 1992 novel *Snow Crash* and aligns with Matthew Ball's recent visions.

3 Methodology (In Progress)

The current research builds on three data sources at two different phases in time. At stage 1, we integrated insights from two sources: First, we conducted more than 80 semi-structured interviews with industry experts with various backgrounds on XR and spatial computing. Second, we analyzed articles in predominantly practitioner-oriented publications (e.g., *Forbes*, *Times*) and online outlets (e.g., The Verge).

At stage 2 (currently in progress), we aim to interview a limited number of top-level technology managers and consultants to validate and fine-tune our conceptual framework.

4 Preliminary Results

4.1 Delineation of Spatial Computing

Based on our preliminary findings, we conceptualize spatial computing as a space that overlaps with both AR and VR (Figure 1). We argue that the overlap with AR is larger than with VR because AR is based on fixed locations of the physical environment and as such requires a precise anchoring of virtual objects, which aligns well with the essence of spatial computing. On the other hand, even though VR applications form part of spatial computing, VR is independent of physical surroundings and as such not bound to the real environment and restrictions in physical space. Furthermore, as indicated in the figure, we conceptualize the metaverse as a subspace of spatial computing with an emphasis on VR.

4.2 Theoretical Foundations of Spatial Computing

Figure 2 shows our preliminary spatial computing theoretical framework. We identify five core elements of spatial computing: immersion, interactivity, AI integration, real-time data and interactions, and content persistence. The key outcomes of spatial computing are presence and embodiment. Presence can manifest itself in the form of telepresence, local presence, and/or social presence. Embodiment may include technical, social, or extended embodiment. Hence, we distinguish immersion as the technological characteristics and objective quality of media from presence, which refers to a subjective, psychological state. These findings lead to four distinguishable spatial computing strategies for firms,

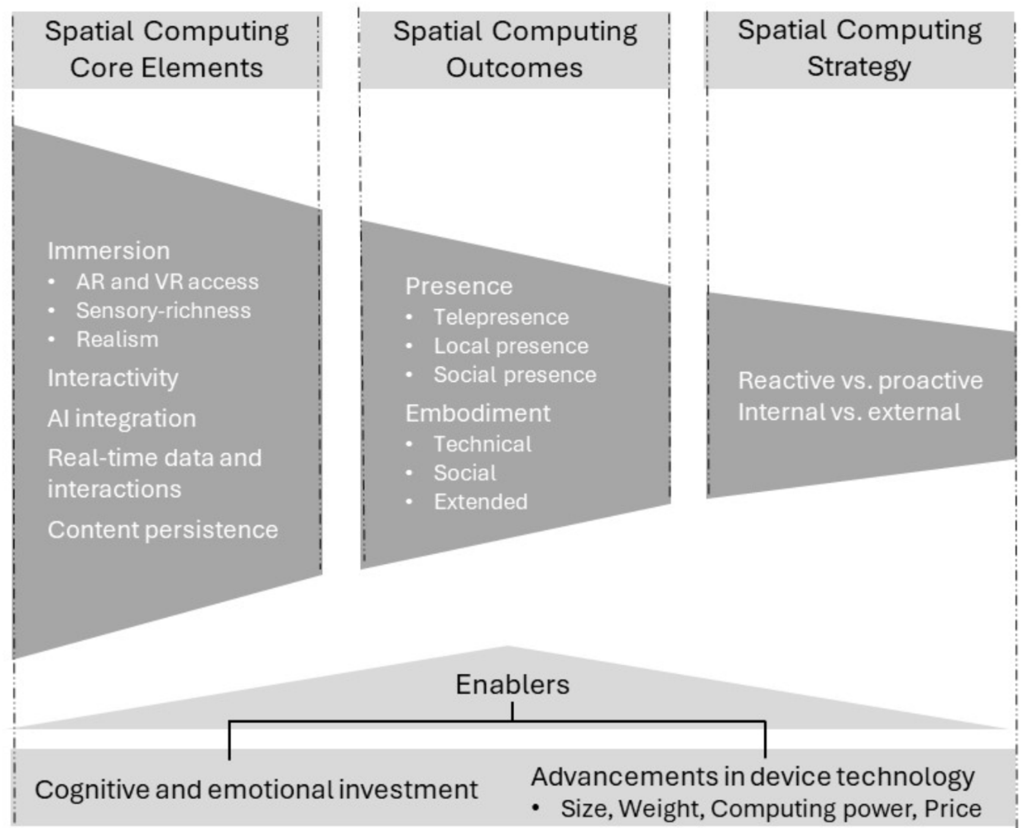

Fig. 2. Preliminary spatial computing theoretical framework.

which we briefly discuss in the next section. In addition, we posit that cognitive and emotional investment of users, as well as advancement in device technology (e.g., relating to size, weight, computing power, and price) are important enablers of spatial computing.

4.3 Implications for Stakeholders: From Spatial Computing Theory to Spatial Computing Strategy

Our preliminary findings suggest that firms can strategically leverage spatial computing along two distinct dimensions: (1) internal vs. external and (2) reactive vs. proactive. These dimensions give rise to four generic strategies, each corresponding to a prototypical use case (Figure 3). Firms that focus on an internal, reactive use of spatial computing may focus predominantly on optimizing core operations, whereas firms that focus on an internal but proactive use tend to employ spatial computing in more innovative ways. Furthermore, firms that use spatial computing externally may be more reactive (e.g., by analyzing customer data that are automatically gathered when customers use spatial computing devices), or they may be more proactive and use insights from spatial computing for the development of new products, new communication modes, or new business models.

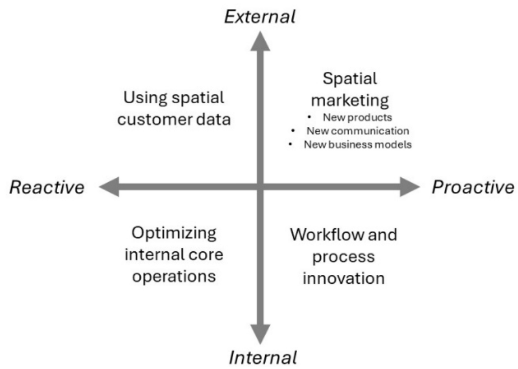

Fig. 3. A guiding framework for spatial computing strategy.

5 Future Research Directions

Although space restrictions prevent us from discussing future research directions in detail, our findings highlight numerous opportunities for both academia and practitioners. These range from better understanding the psychological, physiological, and social processes of consumers using spatial computing devices to exploring how firms can strategically leverage these technologies.

References

References are included in the full paper and/or available upon request.