Original Article

From the Intercellular to the Extraterrestrial: The Need for Interdisciplinary Spatial Study

Space and Culture
1–14

DOI: 10.1177/12063312251363083
journals.sagepub.com/home/sac


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Abstract

There is a critical need to reframe the future study of socio-spatial relations. Current constructs connected to specific disciplinary traditions are often constrained by one-dimensional approaches. The purpose of this article is to share and provoke new forms of socio-spatial study premised on interdisciplinary exchanges. Lefebvre proposes that to discuss space is to analyze the interactions of material environments, mentalities, and social practices. But such enquiries demand myriad analytical tools, and we contend that the study of space requires a reconfiguration of disciplinary parameters, including a willingness to reach across methodological boundaries. We offer two illustrative case studies. One understands the social inhabitation of space as something microscopic and occurring within our cells. The other uses anthropological research to understand how non-Western cultures conceptualize so-called "outer" space in relational terms. Our approach offers new perspectives on socio-spatial relations and a wider understanding of how humans interact with and within space.

Keywords

socio-spatial, research agenda, futures, interdisciplinary

Introduction

The purpose of this article is to explore new interdisciplinary opportunities for the future of socio-spatial studies. It has become commonplace in recent decades to note the increasing scholarly interest in space as both an object of study and as a tool for analysis (Guldi, 2010; Nieuwenhuis & Crouch, 2017; Warf & Arias, 2009). Numerous disciplines have explored the effects of an ongoing "spatial turn" on their research methods and priorities, and there is now an extensive literature describing various fields' interests in space, from law to health policy, from international relations to energy research (Acharya & Panda, 2022; Bridge, 2018; Brigg, 2020; Filippi, 2022; Knott, 2010; Philippopoulos-Mihalopoulos, 2011; Richardson et al., 2013; Withers, 2009).

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One consequence of this proliferation is that research on space has become both conceptually extensive within and across disciplines and, relatedly, ever-more specific as researchers seek to demarcate their focuses and methods. While the conceptual discourse on space grows ever-more sophisticated through this expansion and demarcation, there remain comparatively fewer empirical examples that offer analytical guidance on ways to study the interdisciplinary aspects of complex spatial phenomena.

In this article, we discuss the analytical benefits of two kinds of empirical enquiry explained in the sections below as proposed case studies. The aim of the case studies is to enable new kinds of empirical and therefore conceptual understandings of spatial studies. As discussed in section "Future constructs of space study." To position these, we begin—as many works on space do—with Henri Lefebvre, showing how the questions arising from Lefebvre's legacy facilitated conversation between the authors, each of whom works in a different academic field (history, architecture, law, design, biology, engineering, psychology). We strove to understand more fully what spatial research looks like in each other's disciplines, and to identify points of correspondence and divergence. The article then presents case studies of our disciplinary encounters. What does it mean to think about space at a cellular level, and how might work on cellular biology inform research on the lived experiences of space? What happens if we conceptualize extraterrestrial space using non-Western indigenous cosmologies, rather than more familiar technological and territorial frameworks? We are not seeking to establish a programmatic research agenda based on the insights from these examples. But we are making a case for the necessity of interdisciplinary collaboration in the pursuit of socio-spatial enquiries.

Henri Lefebvre and the Problem of "Space"

The legacy of Henri Lefebvre (1901-91) exerts considerable influence on contemporary socio-spatial studies (Goonewardena et al., 2008; Schmid, 2022, pp. 2–3, 34–39, 52–55, 248). Much of Lefebvre's (1991) appeal as a spatial theorist lies in his often-quoted dictum that "(social) space is a (social) product" (p. 26). At its simplest, the phrase proposes that space cannot be abstracted from social context, but it also insists that space is *produced* by social interactions. Such an argument fits neatly within ideas about the social construction of knowledge, the assumptions of which have been particularly influential in the humanities and social sciences since the 1970s, but which have also extended to the natural sciences and even to mathematics (Berger & Luckmann, 1967; Ernest, 1998; Gergen and Gergen, 2003; Golinski, 2005; Hacking, 1999).

Lefebvre's point, however, is not just that spatial knowledge, environments and experiences can be socially produced. He also argues that space is productive in and of social practices: "social space *per se* is at once *work* and *product"* (Lefebvre, 1991, pp. 101–102; see also Mullis, 2021, p. 331; Stanek, 2007, p. 463). *The Production of Space* explores—and does not always resolve—complex questions about the mutual contingency of space and society which are not easily reduced to a mantra about the social construction of space. Lefebvre is suspicious, for example, of applying the techniques of literary criticism or cultural studies to space; trying, that is, to decipher social space by "reading" the "messages" encoded in it. Such an approach potentially "reduce[s] space itself to the status of a *message*" rather than something lived and experienced (Lefebvre, 1991, p. 7). He worries that a focus on the "intervention of humans" occludes our understanding of "(physical) natural space," an argument which proposes a kind of space which precedes social production (Lefebvre, 1991, pp. 30–31). He wonders whether social space is predicated on language: "is it a precondition of social space or a formulation of it?." In other words, does the social production of spaces define the way we speak about them; or does language precede and thus shape the social expression of space? (Lefebvre, 1991, pp. 16–17).

Most crucially, Lefebvre is aware that to talk about space is to encompass a range of phenomena. One can discuss physical spaces (Lefebvre's own examples are "nature, the Cosmos"); specific material environments; mental spaces (which includes "logical and formal abstractions"); spaces where social practices occur (and which are created by those practices); spaces as perceived by the senses; spaces "of the imagination such as projects and projections, symbols and utopias" (Lefebvre, 1991, pp. 11–12). Each of these requires different analytical tools: the techniques required to examine a "thing in space" are not the same as those needed to study a "discourse on space." And even explanations of how the "production of space" operates in practice might differ depending on disciplinary priorities: think, Lefebvre (1991, pp. 37–38) says, of how differently an ecologist and a historian might explain the development of urban environments. These branching topics and methodologies prompt Lefebvre's (1991) concern about a surfeit of spaces jostling for investigation: "we are thus confronted by an indefinite multitude of spaces, each one piled upon, or perhaps contained within, the next: geographical, economic, demographic, sociological, ecological, political, commercial, national, continental, global" (p. 8). At best, the analytical task is overwhelming; at worst, it is so all-encompassing that it becomes unspecific and methodologically opaque.

Among Lefebvre's many enthusiasts and popularizers, some have offered clarifications or developments of his central concerns. Edward Soja's work is especially notable for its vocabulary. Soja discusses "a First space perspective and epistemology, fixed mainly on the concrete materiality of spatial forms, on things that can be empirically mapped," and a Second space perspective concerned with "ideas about space," "mental and cognitive forms," and "'imagined' representations of spatiality." Concerned that disciplined analyses of space tend to bifurcate into one of these two positions, Soja (1996) instead makes a case for what he calls "Third space" as an alternative approach that "draws upon the material and the mental . . . but extends well beyond them in scope, substance and meaning. Simultaneously real and imagined and more" (pp. 6, 10–11).

Critics have taken issue with Soja's terminology—"Third space" in particular is described as "a slippery term" (Latham, 2004, pp. 272–273)—but his project is clear-sighted about the magnitude of socio-spatial studies. His own study of real and imagined Los Angeles analyses the city from the perspectives of post-Fordist industry; globalization; urban planning (and "radical" appropriations of it); social inequalities; justice, law enforcement and state power; and what he calls the "hyperreal scamscape of simulations and simulacra" (Soja, 1996, pp. 21–22). He draws on a dizzying array of source material—historical texts; photographs; maps; *flâneur*-like impressionistic wanderings, architecture; city design, cultural theory, his own and others' memories—and presents his findings as chronology, itineraries, diagrams, photographs, visual analysis, exhibition curation, and even poetry (Soja, 1996, pp. 186–320). Soja's discussion highlights the enormous scope of any potential spatial enquiry, a challenge which stretches within and across traditional disciplines.

The problem, then, is that spatial analysis can encompass a wide range of subject matter—the physical, the conceptual, the social, the cultural, all of which are to some extent interrelated—and it also draws upon numerous types of source material or data, many of which require specific disciplinary or methodological knowledge to interpret. It is little wonder that some approaches to spatial analysis become narrow, focused on mono-dimensional or easily observable understandings of space (Benyon, 2022; Soja, 1985). Too often, these approaches neglect the transformative possibilities of thinking about space's many aspects and instead try to fit it within existing disciplinary expectations: the traction within cultural studies of the mantra "(social) space is a (social) product" comes to mind here (Susen, 2021). Conversely, more ambitious studies which attempt greater breadth must continually fight against a lack of specificity about what kinds of "spaces" are being discussed—a problem detectable even in *The Production of Space* itself.

Future Constructs of Space Study

It seems to us that if we are to explore an approach or approaches to spatiality which genuinely encompass the empirical, the representational, and the social, we need to do so by combining the perspectives afforded by different disciplinary approaches. This is an endeavor which is beyond any one field or subfield: it requires analytical rigor about precisely what kinds of space are being discussed; but also, the scope to reach across and combine disciplinary perspectives and methodologies to understand the different facets of a space. The potential gains here are very significant. They might include, for example, a fuller understanding of spatial affect, and thus how spaces "produce" cultures as well as the reverse (Shilon, 2023). Or how multi-dimensional socio-spatial relationships might account for cognitive and sensory experiences (Spence, 2020). Or how certain principles of human-space interaction might influence the imaginative processes of architects and engineers as they design both spaces and technological artifacts to use within those spaces. The future is largely influenced by those who make design decisions regarding the development of products, systems, or technologies. To understand and influence the rationale behind those decisions, we need to appreciate that decision-makers operate within the contexts of their own spatial perspectives and activities (Pereira & Hargreaves, 2024; Umbrello, 2020).

In this article, we offer two case studies with far-reaching possibilities for socio-spatial study. We have been inspired in part by the anthropologist Gísli Pálsson's (2009) remark that with "most of the habitat of the globe . . . charted and conquered, humans are returning their attention to the 'remotest corners' of both living organisms and outer space" (p. 69), and consequently our case studies turn first toward cells in the body, and second toward the extraterrestrial cosmos. The point here is not simply that spatial analysis extends to the microcosmic and the macrocosmic. Still less are we suggesting programmatically that all socio-spatial studies must necessarily examine space at very large and very small scales. Our argument is that by combining disciplinary focusses and methods in unexpected ways, we can facilitate new opportunities for socio-spatial study.

Our first case study discusses life at the cellular level in terms of spatial environment. Cells are often studied in biological and bioengineering studies in very specific confined spatial arrangements. These arrangements have specific impacts on cellular behavior and interactions and thereby on human behavior, although links between cellular analysis and studies of how humans interact in buildings (for instance) have yet to be combined. We argue that by engaging more fundamentally in biological studies of cells in spaces they inhabit, we may enable novel understandings of how to design for the spaces humans inhabit. For instance, studies of cell behavior on specially designed surfaces, where single cells move repeatedly between two connected zones, show that even when the zones are equal in area, differences in shape and orientation can significantly affect how long cells remain in each zone and how they move between them. The ratio between the available area and the size of the cell influences overall occupancy, but elongated or angular shapes such as triangles or rectangles (in contrast to squares or circles) introduce directional biases by affecting the cell's internal organization and sense of direction. In short, space is not neutral: its outlines, angles and proportions actively shape how cells behave over time (Fink et al., 2020).

It is well established in biology that cells and their extracellular surroundings continually influence one another, and by studying these interactions we can better understand how microenvironmental conditions affects cellular dynamics. Those conditions can, for example, influence cell development and in some cases the behavior of cancerous cells. Furthermore, genetic diversities can shape the spatial properties of cellular environments. This, in turn, can affect cell communication, with implications for individuals' physiology and behavior. Some such genetic predispositions can affect an individual's sensory perception—how he or she perceives, touch, pain, or temperature for example. This case study alerts us to the complex interactions of

environmental and genetic influences, not only in how bodies develop at the cellular level, but also in how spaces are experienced by an active subject. It suggests that bodily experiences may be to some dependent on spatial interactions at a very small scale, and that to understand some larger-scale spatial experiences we need to study cells.

While the first case study looks at the body from the inside and the very precise biological examination of confined spaces, the second study looks beyond the body, and toward the unknown boundaries of the potentially infinite. It focusses on the exploration of "outer" space, and particularly on the ways in which an extraterrestrial context allows us to reassess fundamental ideas about how humans relate to Earthly spaces: for example, ideas about sovereignty, the body, and transcendence. The language of "outer" space suggests the continued conceptual grip of pre-Copernican anthropocentrism. And certain spatial ideas in Western science—characterized by Lefebvre as "abstract space"—treat outer space as a site to be measured, cataloged, and acquired. Insights from anthropology can, however, help us understand so-called "outer" space in new ways, particularly by foregrounding how non-Western cultures conceptualize the cosmos in relational terms as a site of "lifegiving connections" (Bawaka Country Including et al., 2020, p. 2). This, in turn, opens new ways of thinking about and experiencing space, seeing planet Earth as part of a wider relational space ecology (Battaglia et al., 2015). What we show through these two case studies is that by approaching socio-spatial relations from cross-disciplinary perspectives, new research questions and agendas emerge about the future of spatial study.

Method

We recognize the empirical and theoretical challenges inherent in the proposition discussed in this paper. Many scholars have argued for the need to employ different methods and epistemologies to better understand the scalar and temporal characterizations of space (Stock, 2015). But existing approaches—especially those located firmly within a specific disciplinary framework—cannot always facilitate the understandings and concepts necessary for a full analysis of socio-spatial relations. The value of cross-disciplinary approaches as proposed in this paper, is not just that future study may enable new methods, but also that it has the potential to generate new ways of thinking about and conceiving of space—whether in built or natural environments, whether in physical or virtual terms. In this paper, our case studies provide indications of how the study of space-futures could break new conceptual ground.

Drawing upon "methodological tactics" previously used successfully by the second author (Oliveira et al., 2023) we have relied on "grounded theory that aims to *generate, identify*, and *trace* (our proposed) conceptual basis." Our "tactics" involve multiple dialogues between the authors carried out between 2022 and 2024. These dialogues explored alternative ways of understanding the social inhabitation of space and they also helped to articulate some of the most important theoretical and empirical obstacles and constraints. The dialogues were facilitated and initially convened by Oliveira, who brings expertise in architecture, seeking to explore the diverse disciplinary interpretations of social inhabitation of space and how these dialogues may offer new approaches and new analytical tools.

The initial conversations were tentative, and emerged through long-term collaborations with Chatzimichali, design engineer, trying to establish ways human inhabitation of space could be studied to take account of genetic predispositions and cellular functioning in the highly bounded spaces cells inhabit as well as in unbounded extraterrestrial spaces. These initial conversations then led to a mapping of missing expertise and identified scholars in spatial history (Stock), space and law (Vermeylen), cellular space (Witte) and multisensory experiences of space (Spence). Several one-to-one and group discussions were held to establish commonality in epistemological and ontological positions in terms of (1) how social inhabitation of space is studied in history,

architecture, biology, law, and psychology; (2) how these different approaches revealed areas of oversight or conflict; and (3) what remained unaccounted for or poorly understood.

We then proceeded to scoping reviews of literature: not just seminal work by Lefebvre and others in geography, urban studies and architecture but also research in psychology, biology, and law which is less well known in spatial study discourse. The empirical cases emerged as settings through which the social inhabitation of space could be explored more specifically—in particular, to understand more about what remains unknown regarding the human experience of inhabiting space. Our discussions and explorations gradually focused on: how the cell in the body interacts with space and how this might manifest in the human inhabitation of space; and how human experience of the infinite might provide new ways to relate with space. These cases are very different: one studies a very known confined geometry as discussed in section "What happens within cells?," the other an expansive and less well "measured" one in section "How does the extraterrestrial change what we understand as space?" Crucial insights then developed through further literature reviews and by using an Advisory Board and independent peer review to expand our thinking, ensure credibility, and provide peer-evaluation.

Following stages *of generating* and *identifying*, the conversations began *tracing* the analytical perspectives of these cases. At this stage too, the first author prepared notes on existing approaches to space derived from Henri Lefebvre. These notes clarified our proposed case study approach based on interdisciplinary exchange. Throughout, the range of disciplinary views and positions was crucial; we recognized early in the process that the root of many existing problems in spatial analysis lie in the interdisciplinary nature of the phenomenon.

The resulting assemblage methodology (Buchanan, 2020) we have adopted is one that is often used whenever the aim is to develop new conceptual insights within complex, multi-dimensional fields of study. While the records kept do not account for all the work done so far in social sciences on socio-spatial phenomena, the aim of our approach and therefore this paper is not to provide an overview or review of work done to date. For this reason, we have chosen to write a position paper rather than a mapping study or a systematic literature review. Instead, we set out a research agenda which has been distilled through a series of dedicated conversations among the authors. Our overall purpose is to motivate and guide future research by scoping ways in which we can understand the social inhabitation of space more fully through interdisciplinary exchange.

What Happens Within Cells?

Our first case study analyses space at the cellular level and considers the importance of this analysis for the future study of socio-spatial relations. Though there has been extensive work in cellular analytics, they have tended to be confined to the realms of biology. Cells have particular behavioral dynamics that are shaped by spatial geometry—by understanding this in the context of the human and their inhabitation of a room for instance, we could better understand the social dynamics involved as informed by biology.

In this respect, the proposed case study, builds on work in which "distance from biology is no longer seen as a prime marker of social and cultural theory" or practice (Thrift, 2008, p. 174; Turner, 2002). Life unfolds dynamically, with cells as the smallest structural and functional units, capable of existing autonomously within a precisely defined spatial environment. Within this tightly specified space, cells and the surrounding extracellular matrix perpetually engage in a mutual exchange of influences, each constantly shaping and being shaped by the other. This ongoing interaction is driven by a complex interplay of physical and chemical factors—such as molecular compositions, mechanical forces, and topographical features—defined and varied within this spatial framework alongside other cellular inhabitants (Witte et al., 2021).

Acknowledging the role of spatially defined stimuli expands our understanding of how cells respond to extracellular cues throughout their lifetimes, highlighting the importance of the spatial

environment in cellular dynamics. The interaction between genetic factors and environmental conditions leads to deterministic outcomes, where confinement shapes cellular behavior by influencing thermodynamic principles and energy dissipation. This allows cells to perceive and adapt to their surroundings. Spatial agency is critical in mechanobiology, where the focus is on how cells sense and respond to mechanical forces within their environments.

In confined experimental settings (not in situ), where spatial parameters such as confinement geometry, temperature, cell types, and chemistry are precisely controlled, we observe firsthand how mechanical stimuli directly affect cellular behavior and tissue development. The confinement space is proportionally adjusted to correspond with the size range of individual cells, from 10 to 100 μm. By manipulating these spatial confines, we can explore variations in cell morphology, migration patterns, and signal transduction pathways, effectively mirroring the cellular responses observed in more complex, natural biological settings. For instance, the migratory behavior of breast cancer cells within a well-defined confined microenvironment contrasts starkly with that of non-cancerous cells (Brückner et al., 2019) similarly, varying degrees of softness in otherwise chemically identical environments lead adult human stem cells to differentiate into fat cells in softer settings, whereas in harder settings, they become bone cells (Zhao et al., 2014). Furthermore, introducing an additional cell of the same lineage and type to either scenario dramatically alters the entire pattern of cell dynamics (Brückner et al., 2021). Most intriguingly, cells transferred from different spatial environments into a new, identical one exhibit markedly different behaviors, as they carry a spatial physicochemical memory shaped by their previous conditions (Yang et al., 2014).

This foundational understanding of spatial influences in cellular dynamics has consequences for how we might think about socio-spatial relations at the supracellular level. For example, it becomes important to consider how genetic diversity shapes the spatial properties of cellular environments, such as tissue viscoelasticity. Guided by genetic variations, the spatial parameters of the microenvironment lead to nuanced differences in cell communication within these environments, thus resulting in diverse physiological and behavioral outcomes across individuals of the same species. Hypermobile Ehlers-Danlos Syndrome (hEDS) is a genetic connective tissue condition which causes joint hypermobility, joint instability, and chronic pain. For individuals with hEDS, genetic predispositions directly influence the mechanical properties of the cellular environment, altering extracellular mechanics and creating varied supracellular architectures in tissues and organs (Malfait et al., 2020).

The genetic makeup of individuals with hEDS therefore leads to unique mechanical properties in their extracellular matrix. This has significant effects on how they perceive sensory information such as touch, pain, temperature, and proprioception (awareness of the body's position in space). Due to these altered mechanical properties, an individual with hEDS may not register sensations like a full stomach or bladder, or they may fail to detect immediately a first-degree burn. This illustrates the impact of genetic factors on the spatial properties of cells and tissues, which, in turn, influences sensory perceptions and physiological thresholds. When placed in a spatially defined built environment or interacting collectively with others—whether of the same species or not—in a shared space, their sensory perceptions are markedly different. This neurodiversity, emerging from spatial micro-scale confinement influenced by genetic factors, exemplifies the complex interplay of spatial interactions—at the cellular, supracellular, and terrestrial levels—in shaping individual responses.

The analytical value of this approach is in its ability to bridge the micro-scale dynamics of cellular environments with broader socio-spatial phenomena, fundamentally reshaping how we understand the interplay between space, genetics, and sensory perception. This method positions spatial environments at the cellular level as active and essential participants in shaping behavior—not just of individual cells but of collectives and the systems they form. By integrating mechanobiology, genetics, and spatial studies, it reveals how spatially defined stimuli, including

mechanical forces, chemical gradients, and cell-cell interactions, orchestrate complex behaviors and emergent properties.

This approach scales these cellular insights upward to challenge conventional socio-spatial theories, demonstrating how genetic variations and microenvironmental factors shape sensory perceptions, adaptation, and interaction at larger scales. It opens new avenues for rethinking how spaces—biological and built—can better accommodate the diversity of experiences, offering transformative potential for inclusive design. By reframing spatial environments as dynamic agents across biological and societal systems, this perspective offers a new understanding of the interconnected layers of space, behavior, and identity, paving the way for a socio-spatial theory that bridges disciplines and scales.

How Does the Extraterrestrial Change What We Understand as Space?

Our second case study argues that by expanding our thinking about space beyond the terrestrial, we become more sensitive to the idea that the socio-cultural construction of space is always related to the non-living spatial, environmental, and ecological *umwelt*. As Roe (2023, p. 99) reminds us, Lefebvre (1991) argued that human societies are fundamentally interconnected with the universe and cannot be understood in isolation from it. Similarly, cosmology, which studies the universe, must account for human societies rather than treating them as separate (pp. 13–14). This suggests that space is not just a social construct but is embedded within a larger cosmic framework. This perspective has long informed anthropological debates about how spatial meaning extends beyond human social structures and includes cosmic and natural forces (see, for example, Vermeylen, 2017) but is often obscured in western theories of space. Thinking about space beyond Earth offers an opportunity to reframe our connections with the cosmos.

Lefebvre's conceptualization of space, particularly through his distinction between absolute and abstract space, provides a valuable framework for understanding extraterrestrial space (Dickens & Omrod, 2016). Lefebvre (1991) defines absolute space as an organic, sacred, and historically embedded spatiality, often grounded in natural sites with "intrinsic qualities" (p. 48). In contrast, abstract space emerges from capitalist accumulation, transforming space into a resource to be exploited, controlled, and dominated (pp. 49, 52). This distinction remains pertinent in the contemporary era, where outer space is increasingly subjected to the logics of capital expansion, territorial governance, and militarization (Dickens & Omrod, 2016: 445–446).

Sputnik I, launched by the Soviet Union in 1957, was the first satellite to orbit Earth. This event is often seen as the beginning of the Space Age, marking a shift how humans conceptualized their relationship with the cosmos. For sure, the launch is comprehensible in terms of Lefebvre's ideas about abstract space. Sputnik symbolizes that space—in this case "outer" space—is not an empty and neutral container, but is a social product shaped by power, history, and ideology. Sputnik thus contributed to the further abstraction of space as a site of geopolitical competition, scientific accumulation, and economic expansion. This technological conquest of outer space represents for many space scholars "the ultimate victory of abstract space" (Roe, 2023: 109; Shaw, 2008: 1150).

Kearnes and van Dooren (2017, pp. 178–179) draw on Arendt's (1958, p. 10) interpretation of Sputnik's launch to critique the rigid distinction between emptiness and fullness in space. Arendt saw the launch not as a mere technological achievement of a simple expansion into the unknown but as the realization of long-held human imaginings about the cosmos. Rather than viewing space as an empty void to be conquered, she argued that it was already morally, philosophically, and imaginatively full before human arrival. According to this view, space rather than being a blank slate for colonization or exploration, space is already rich with human dreams, theological

reflections, and speculative narratives. This perspective aligns with Dickens and Omrod's (2007) critique of Western spatial imaginary which portrays space as an external and uninhabited void, reinforcing notions of human dominance over nature.

It is worth noting though the abstraction of space began long before Sputnik. Geometry, astronomy, and cosmology have historically shaped how humans conceptualize space. Therefore, the process of abstraction of space was not sudden with the technological advancements of outer space exploration but it was rather gradual and cumulative. Dickens and Omrod (2007) posit that the idea of abstract space is a socially constructed perspective that is rooted in Western modernity. For example, while in Medieval cosmology the cosmos was structured in accordance with divine order and spiritual beings, during the scientific revolution, knowledge about the cosmos became increasingly mechanistic, and space has since been perceived as isolated and an empty vacuum (for a historical overview see, for example, Kragh & Overduin, 2014). As Dickens and Omrod (2007) explain further, this portrayal of empty frontiers mirrors the way that Western powers have justified territorial expansion on Earth. Through the rise of Enlightenment philosophy and the scientification of knowledge, space has gradually been transformed into a commodity for control and exploitation. But as critical geographers (Klinger, 2019) and anthropologists of space (Olson & Messeri, 2015; Praet, 2023) claim, this Western notion of space as an external and empty realm can be challenged by looking into space from a non-Western perspective. In Aboriginal "Sky Country," the stars, land, and human societies are intimately connected and Western notions of space as an external void are clearly rejected by many Indigenous communities. As Bhathal (2006) describes,

> [m]odern physicists and astronomers would probably have difficulty in empathizing with the Aboriginal conception and origin of the universe. Their universe is not the universe of the Big Bang, inanimate matter, dark energy or accelerating expansion. In Aboriginal astronomy the origin of the universe goes back to a time called *Dreaming*. (p. 528)

Haynes (2000) further clarifies that Aboriginal peoples' spatial knowledge is not framed through numerical coordinates or fixed temporal markers but through relationships, stories, and social obligations that extended into the "skies." Space, for Aboriginal peoples, is not an abstract, empty expanse but a lived, meaningful continuum where terrestrial and celestial reams are interwoven. The *Dreaming* provides a framework for this understanding, reinforcing the idea that space is not just physical but above all cultural, spiritual, and social. This perspective challenges dominant Western notions of space as something to be measured, segmented, and controlled. Unlike Western astronomy, which isolates celestial objects and emphasizes precision, Aboriginal astronomy is integrated into a worldview that prioritizes through the *Dreaming* interconnectedness, continuity, and symbiosis between the land, the sky and human and nonhuman communities (Haynes, 2000, pp. 53–54).

Aboriginal space, therefore, also calls into question Lefebvre's spatial dialectic between absolute and abstract. Lefebvre's approach to space is based on Eurocentric assumptions about the historical and linear transformation and social reproduction of an absolute to an abstract space. Engaging with anthropological approaches of space, such as Australian Aboriginal cosmologies, reveals an alternative model of space that is relational, embedded, and reciprocal, rather than extractive and abstract. Such insights about space could contribute to a more ethical and sustainable governance of space which moves beyond Western frameworks of accumulation that perceive outer space as empty and void toward models that acknowledge the long-standing interdependence between human societies and the cosmos.

Therefore, in this case study we note that Indigenous cosmologies offer new ways to understand space and society from a relational perspective (Bawaka Country Including et al., 2020; Timko et al., 2022). This view exposes and questions our anthropocentric and often exploitative

experience of space and can change space from a "site" that can be known, grasped, and colonized, to a space wherein both human and nonhuman, living and non-living entities come together. Space in this latter sense becomes "a place that brings into being the lifegiving connections between people and place (Bawaka Country Including et al., 2020, p. 2)." Aboriginal cosmologies position celestial bodies as active participants in the social and ecological order, challenging the anthropocentric framing of outer space as an object to be dominated. In other words, Indigenous spatial understanding resist Lefebvre's teleological trajectories that subsume absolute space into an abstract space, a framing that has also defined our exploration and exploitation of outer space.

This is of relevance because it is not unforeseeable that in the future we may have permanent habitations in outer space. Our imagination has always been sparked by the idea of human settlements on the Moon or Mars (Geppert, 2018). Studying humans' interactions with space in an extraterrestrial context will allow us, as Buchli (2021) argues, to revisit some of the fundamental concepts that underpin some of our understandings of how humans interact with Earthly spaces: these include, but are not limited to, transcendence, kinship, materiality, architecture, sovereignty, and the body. So far, these concepts have mostly been studied from a terrestrially bound lens (Buchli, 2021; Gorman, and Gorman & Walsh) but we now have the opportunity to expand our knowledge beyond terrestrial geometries of time and space. This will not only provide new knowledges about humans' interaction with outer space but will also provide, as anthropologists of outer space have already argued (e.g., Abramson & Holbraad, 2014; Battaglia et al., 2012; Buchli, 2021; Gorman, 2009; Messeri, 2016, 2017) new epistemologies about the convergences and co-presence that exist between terrestrial and extraterrestrial environments (Horwitz & Singley, 2004; Taylor et al., 2020).

At this point, it is also crucial to note that there is an important point of correspondence here with our first case study. If we want to understand how humans interact with and within space, we need to take advantage of how and where different disciplinary perspectives site those interactions. If the cellular level potentially affords new insights for socio-spatial study, so too can extraterrestrial perspectives reframe the ways we conceptualize ourselves and our surroundings. And we can further begin to understand how the body and the cosmos interact or, in Pérez-Gómez's (2016) words, become attuned to one another. Anthropological studies of outer space provide crucial insights here because they show the complex entanglements which occur when human life and human bodies exist within extra-territorial habitats (e.g., Gorman, 2009; Gorman & Walsh, 2023).

Future studies of space can therefore learn from Indigenous communities and disciplines such as anthropology and archeology (Buchli, 2021). In many non-EuroAmerican cultures, the transcendent and celestial are co-present and as Gorman (2009) has illustrated, the terrestrial and the extraterrestrial converge into a common field of inhabitation. There are accounts of Indigenous peoples' cultures whose shamans have been traveling to the Moon long before NASA (e.g., Smiles, 2023). In other words, by engaging with anthropological studies of outer space and non-EuroAmerican cosmologies we can become more aware of the co-constitutive entanglements between micro (cells) and macro (extraterrestrial) spaces. We can gain new knowledge of what forms of existence emerge from new constellations of body and technology, and how this generates new knowledge about the social and its behavior with and in space. Ultimately, such perspectives contribute to an ongoing post-Copernican revolution which resists anthropocentrism and displaces the Earth and the human as the center of productivity. Through the study of what it means to be human in extreme spaces, Earth and the human are decentered and new models of society, cosmology, and body may emerge.

Conclusion and Discussion

The main goal of this article is to explore how we might rethink approaches to the social inhabitation of space. In particular, we need new frameworks that reach across disciplines and consider socio-spatial relations from new perspectives. Our chosen examples look at microscopic and cosmic spaces, and discuss how cross-disciplinary insights can not only reconfigure the analysis of specific sites but can also reframe the scope of spatial study itself. Spatial analysis encompasses a wide range of physical, conceptual, and social elements. By breaking disciplinary silos and highlighting the interconnectedness of spatial enquiry we can develop new interdisciplinary methods to analyze more fully the spatial phenomena which shape ourselves, our world, and our futures (Marshall, 2023). The examples provided here are conceptually significant because they show that spatial enquiries need to be specific about the kinds of spaces being discussed, and that spatial research agendas must be context-driven. This approach provides room for different disciplines to explore a specified context from different perspectives, with a genuine openness as to how each other's priorities can illuminate shared interests. Our case studies are intended to provide brief examples of what that looks like in practice without necessarily prescribing a fixed procedure.

Overall, our contention is that there are epistemological advantages in combining disciplinary insights to strengthen the coherence and collective relevance of spatial enquiries. Our case studies show that understanding space and socio-spatial relations is a task for disparate fields, and by bringing different disciplines into dialogue over specific spaces, we can begin to appreciate the depth and richness of spatial knowledge and experience. Beyond these epistemological advantages, further value lies in the practical application of that knowledge. An interdisciplinary approach can also lead to innovative design approaches that not only fulfill functional requirements but also enrich cultural and sensory experiences. For instance, by understanding in-depth how spaces shape cultures we can guide the creation of public areas that encourage community engagement or response to crises. In addition, recognizing how socio-spatial relationships influence cognitive and sensory experiences can lead to environments or technologies that enhance personalized well-being. By acknowledging the constraints, the boundaries and opportunities within various spatial disciplinary perspectives, we can make more informed choices, ultimately shaping the way we build a future (Gall et al., 2022).

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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