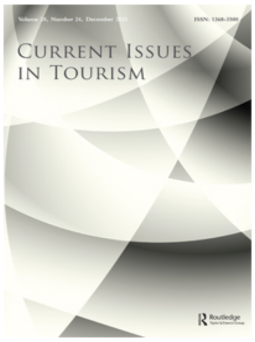

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Cybersickness in metaverse travel

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ABSTRACT

While the Metaverse promises transformative tourism experiences, the physiological challenge of cybersickness presents a significant barrier to inclusive adoption. This conceptual paper defines cybersickness in the Metaverse as a condition integrated into the virtual tourism experience itself, operating through locomotion, immersion duration, and perceived motion, rather than a transit issue. We develop a theoretical framework, comprising an Affordance Duality Matrix and a four-dimensional process model, that synthesises Affordance Theory with Sensory Conflict and Postural Instability theories. A key contribution is identifying the temporal paradox where features enabling high-fidelity immersion transition into physiological constraints over time. Furthermore, the framework synthesises these established theories by showing that specific technological designs determine whether conflict leads to instability via sequential or feedback-looped pathways. Finally, the research posits that cybersickness creates a biological digital divide, excluding vulnerable populations based on neurological tolerance. We conclude by advocating for user-centric design to ensure inclusive Metaverse tourism.

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Metaverse; virtual world; cybersickness; affordance theory; sensory conflict theory; postural instability theory

1. Introduction

Metaverse experiences are seen as the future of tourism, creating entirely new experiences (Filimonau et al., 2024; Kılıçarslan et al., 2024; Koo et al., 2023; Zhang et al., 2024), allowing visiting a virtual destination (Miao et al., 2024; Nazli et al., 2025), and providing virtual access to locations with reduced environmental damage (Go & Kang, 2023). Current conceptualisations of the Metaverse describe spaces that integrate physical and virtual elements with experiences that can move seamlessly between both domains, unlike virtual reality (VR), which is digital-only (Hilken et al., 2022). Metaverse developers aim to create a sense of presence by leveraging visual and auditory cues to engage users (Oh et al., 2023). Simulation of travel in the Metaverse via head-mounted displays, such as VR or extended reality (XR), may cause cybersickness with symptoms such as nausea, headaches, and dizziness (Yildirim, 2020). As head-mounted displays are currently the main tools to access the Metaverse, as well as handheld devices such as augmented reality (AR), this paper focuses on cybersickness from the perspective of these technologies in the specific context of the Metaverse.

Drawing on earlier foundational work on motion sickness in virtual environments (Stanney et al., 1999; Young et al., 2007), recent studies have investigated motion sickness in virtual reality as the

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technology has advanced over the past decade. Main research findings include sensory mismatch as the primary cause (Kim et al., 2020), similar symptoms as classical motion sickness (with variation of individual factors and specific VR content) (Howard & Van Zandt, 2021), and the development of subjective measurement tools (e.g. Virtual Reality Sickness Questionnaire and Visually Induced Motion Sickness Susceptibility Questionnaire) (Keshavarz et al., 2023; Kim et al., 2018), and objective measures through gathering real-time physiological data (Krokos & Varshney, 2022). Although VR is the foundational technology for the Metaverse, it does not offer the multi-user, interactive, always-on, and cross-platform experience enabled by XR, VR, and AR that blends the digital and physical worlds. In addition, travel experiences in the Metaverse have their unique characteristics. However, cybersickness in metaverse travel is yet to be explored.

Alongside optimistic accounts that frame Metaverse travel as a tool for accessibility and inclusion (Chen, 2025), research has begun to reveal the negative outcomes (Hassan & Saleh, 2024). Recent work has proposed a 'Darkverse' concept, suggesting that the solitary nature of Metaverse experiences and the absence of temporal constraints can pose physical and mental health risks. It also suggests regulatory strategies to limit time spent in such environments. (Saleh, 2025). In this paper, we focus on a different, but complementary aspect of this dark side: cybersickness, a physiological response to the sensory and postural stimuli encountered during Metaverse activity. We discuss the need to theorise the mechanisms of cybersickness in Metaverse travel to strengthen the theoretical foundations for more responsible Metaverse design.

The vision of Metaverse travel, which requires long engagements in the immersive virtual world, could be exclusionary to some users, as nausea, oculomotor issues, and other negative effects make the experience inaccessible. Acknowledging that the Metaverse will increase accessibility for some tourists (Dudley et al., 2023; Özdemir Uçgun & Şahin, 2024), the nuanced relationship between the Metaverse and accessibility requires further critical investigation, particularly scholars emphasising the importance of the Metaverse for accessible tourism (Gursoy et al., 2022).

In this paper, we develop an affordance-based theoretical framework for cybersickness in Metaverse travel. The contribution of this paper is an exploration of the cybersickness effects in the context of travel and tourism. While the area has been explored in VR studies (Simón-Vicente et al., 2024), discussions on digital wellbeing in tourism have not yet examined cybersickness (Stankov & Gretzel, 2021). The paper also contributes to the broader discussions of critical information technology, inclusion and tourism knowledge production (Cai et al., 2021) by providing an alternative to the current advocating voices that posit ubiquitous adoption of the Metaverse (e.g. Buhalis, Leung et al., 2023).

2. Motion sickness in travel

Defined as a disturbance in the sense of balance and stability, motion sickness results from conflicts among sensory inputs (Koohestani et al., 2019). Although motion sickness is relatively common during travel, it is under-theorised in the current tourism literature. The nature of motion sickness in travel has coevolved with technology and the emergence of hypermobilities, from speeding up in the corporeal world through air transport to near-instantaneous transit between virtual and physical worlds in the Metaverse (Hatami et al., 2024). In this way, technological developments have shifted sickness caused by mobilities from the transition period to the actual holiday experience at the destination.

In the context of relatively low-speed travel (e.g. rail, cruises), motion sickness tends to occur during the transition between home and the destination. Such motion sickness arises from a mismatch between tourists' perceived stability and stationary activities and the actual sensory input indicating motion detected by the body's vestibular system (Koohestani et al., 2019). In addition, bodily rhythms are experienced and practised in everyday experiences with familiar movements and schedules (Lefebvre, 2013). When these routines are disrupted, rhythmic discord arises, leading to illness (Edensor & Holloway, 2008). Jensen et al. (2015) investigated the concept of rhythmscapes in Interrail travel and found that the subtle, repetitive movement of the train can lead to motion sickness. Differing from the conventional theoretical approach of sensory conflict theory, Lefebvre's (2013) notion of rhythm and rhythmanalysis offers a new perspective to investigate motion sickness in travel by unpacking the state of arrhythmia, caused by a discordance between bodily cycles and environmental rhythms.

The shift to high-speed, long-distance travel has brought new forms of motion sickness. For instance, in space travel, due to the disruption of normal vestibular cues of microgravity, space travellers experience unique challenges of motion sickness (Buckey et al., 2025); in autonomous vehicles, sensory conflict, lack of control, and longitudinal accelerations result in stronger motion sickness than conventional vehicles (Fu et al., 2024).

For certain activities, tourism experiences themselves are highly embedded in the mode of transportation, such as cruise and coach tours or northern light viewings, which lack a clear distinction between transit (relatively hypermobile) and holiday (relatively still). Although studies on motion sickness in cruise (seasickness), road transport, and flights (air sickness) are well documented (see Grandhi & Chaturvedula, 2025; Turner & Griffin, 1999), no studies have investigated it through a tourism lens. Motion sickness, as a relational effect of the affordance between tourists and the transport, affects the entire experience, as it is tied to the transportation mode.

Beyond in situ sickness, our conceptualisation of motion sickness also includes sickness as a result of (hyper)mobilities in travel. In the case of hypermobile travel, drastic changes in environmental perceptions, including temporal and geographical dislocation, lead to a series of mental and physical disruptions not only during the transit, but also at the destination (Janse van Rensburg et al., 2021). Anderson (2015) framed jet lag as a broader term for travel disorientation, incorporating geographical, cultural, physiological and psychosocial negative effects. Studies have been investigating the dark side of hypermobilities in travel, particularly in business travel, such as physical exhaustion, psychological distress, and a sense of lost control (Cohen et al., 2018).

3. Cybersickness in metaverse travel

The mobilities turn challenges the static coupling of time and space, and suggests temporal–spatial compression enabled by the development of technologies of communications and travel (Harvey, 1999), which results in new temporal and spatial configurations. Sickness has been reported as one of the negative outcomes of this drastic alteration of our relationship with time and space (Anderson, 2015). The technological development of the Metaverse has further deconstructed and detached spatial and temporal relations (Zhu, 2022). The Metaverse creates new issues of motion sickness (Shin, 2022) due to intensified time–space compression of pre, during and post-travel mode shifts. With the removal of the physical transit period, motion sickness is further integrated into the travel experience itself. Metaverse tourists may experience heightened motion sickness, which was previously associated with certain stages of travel but is now extended and integrated into the entire travel experience.

While studies examining how technologies lead to time–space compression and detachment are not new (Harvey, 1999), in tourism studies, most discussions are around how digital technologies changed the way we communicate and share travel experiences during holidays (White & White, 2007), studies rarely pay attention to how technologies that seek to simulate spatial–temporal shifts, impose new 'virtual rhythms', have affected bodied experiences, particularly motion sickness. Therefore, with the introduction of the Metaverse, motion sickness can be defined as cybersickness.

Since there are no studies on cybersickness in metaverse travel, the definition is built on three foundations to ensure its rigour. First, the existing literature on Metaverse travel, particularly how Metaverse shape the travel experiences (e.g. immersive, interactive experience, enhance accessibilities, support decision-making and community building) (Buhalis, Lin et al., 2023; Ioannidis & Kontis, 2023); second, the foundational work on cybersickness in VR and motion sickness in travel discussed in the previous sections; and third, the current development and understanding of the Metaverse, and its features (e.g. locomotion techniques, display optics, latency, field of view) (Dhelim et al., 2022; Kim et al., 2024), which determine the sensorimotor conditions under which sickness arises. Due to the lack of empirical understanding of this phenomenon, our conceptualisation both builds on and departs from prior literatures: we retain proven mechanisms but re-specify their operation under metaverse-specific affordances and travel goals.

We identify three modes by which cybersickness may occur in Metaverse travel. Firstly, locomotion techniques can cause cybersickness during Metaverse travel. On the one hand, existing studies have shown that locomotion in VR directly causes cybersickness, particularly during continuous movement (e.g. joystick or steering) or when using semi-natural techniques (e.g. cybershoes, treadmills) that do not align with real walking (Hořejší et al., 2025). On the other hand, studies also suggest that the teleportation technique of locomotion, especially in its instant form, consistently results in a lower level of cybersickness in VR (Caputo et al., 2023). However, Cherep et al. (2020) and Rantala et al. (2021) argue that teleportation's lack of continuous movement cues can disrupt cognitive spatial formation, leading to disorientation and difficulty maintaining awareness of a travelled path. Transferring this understanding to the context of metaverse travel, disorientation is created in the Metaverse by teleporting or jumping from one destination to another, or by switching between virtual and physical spaces within seconds (Christou & Aristidou, 2017). Spatial compression provides a time saving for customers, which is linked to disorientation. Tourists using these systems must constantly adjust their perceptions of socio-spatial relations due to the detachment between temporality and spatiality. Here, we use embodied experience to describe how travellers' sensorimotor engagements with their surroundings couple body and environment, shaping how they perceive and make sense of place (Chen et al., 2023). The embodied experiences of transiting, waiting, and arriving in physical travel, although time-consuming, play a significant role in helping travellers orient to unfamiliar space (Jensen et al., 2015) through sensing, adjusting, and syncing with the new rhythms. The lack of these stationary moments could further contribute to Metaverse cybersickness. By removing these crucial transiting buffering periods, travel disorientation is embedded throughout the entire Metaverse trip, which may result in negative overall travel experiences. In addition, one of the key strengths of Metaverse travel is its ability to leverage various locomotion techniques, such as joysticks, gaze-directed steering, and move-in-place, to create an immersive experience. But all these features come with potential for cybersickness.

Secondly, the duration of planned experiences will amplify sensory mismatch, which is a key factor in cybersickness in AR and VR (Ng et al., 2020). Tourism metaverse researchers present a vision of an alternative immersive space where people can spend a long time, in this case, replacing the corporeal holiday experience (Go & Kang, 2023). While cost savings and risk reduction may be attractive to customers, at present, access to such immersive tourism experiences in the Metaverse is primarily through head-mounted displays. Studies have already shown that prolonged immersion in a VR environment increases the likelihood and severity of cybersickness symptoms, such as nausea and dizziness. Given the prolonged length of holiday experience and the immersive time users spend in the Metaverse (Mogaji et al., 2023), if the issue of sensory mismatch remains unresolved, it will be challenging to sustain continuous, non-disruptive virtual experiences without cybersickness (Christou & Aristidou, 2017). In addition, some might argue that Metaverse travel encourages shorter, more frequent leisure sessions than extended corporeal vocations (Paliwal et al., 2025). If taking breaks from the Metaverse is recommended to mitigate this risk, or if teleportation is used to transport virtual tourists between spaces, the issue of travel disorientation through teleportation remains. Further, prolonged use of VR or AR can also cause oculomotor issues in addition to nausea. While AR users may experience lower levels of sensory mismatch and locomotion is under the user's control, prolonged exposure can similarly lead to headaches or eyestrain (Hughes et al., 2020).

Thirdly, perceived motion during the Metaverse experience may cause nausea. One of the key motivations for travel is seeking excitement, which distinguishes it from the repetitive, mundane everyday life. Studies on Metaverse travel already show exciting potential to engage users in thrilling leisure activities that are often inaccessible or risky in real life (Buhalis et al., 2023). Although it indicates great inclusive potential by engaging with those who have limited physical access, research suggests that virtual experiences such as skydiving, roller coasters, and bungee jumping with forced movements from VR head-mounted display simulations can cause cybersickness and high participant withdrawal rates (Nesbitt et al., 2017). This further extends the previous arguments on sensory mismatch and rhythm discord, in which Metaverse tourists remain still in their physical setting while experiencing acceleration virtually through VR head-mounted displays. Evidence from VR indicates that virtual acceleration (Oh & Son, 2022), high virtual speed (Hughes et al., 2023), and an increase in the ratio of virtual to real movement (Chatterjee et al., 2024) can intensify cybersickness. The thrilling leisure activities in Metaverse travel are not limited to immersive VR environments, as evidence suggests that AR can induce sickness when virtual objects are projected into the physical world (Kaufeld et al., 2022).

4. Methodology

To address the theoretical fragmentation surrounding cybersickness in the Metaverse, this study adopts a conceptual research design defined by Xin et al. (2013). Drawing on Xin et al.'s (2013) typology of conceptual themes, our methodological approach involves four distinct analytical moves: (1) scoping the literature on motion sickness, VR, cybersickness and affordances to map the scope of concepts. We also incorporate a brief historical analysis tracing the evolution from traditional motion sickness to contemporary cybersickness to ground the framework in established perceptual mechanisms; (2) comparing and integrating key ideas from affordance theory, sensory conflict theory and postural instability theory to establish a shared set of mechanisms and vocabulary; (3) constructing an Affordance Duality in Metaverse Travel (Table 1) that links five categories of Metaverse travel affordances to characteristic sensory conflict and postural instability patterns; and (4) abstracting from this matrix into a four-dimensional process model that explains how specific design-body-time configurations shape patterned shifts from enabling immersion to constraining cybersickness in Metaverse travel.

We follow the quality criteria outlined by Xin et al. (2013) to ensure conceptual rigour. Firstly, we emphasise good scholarship through a critical and interdisciplinary review that extends beyond tourism studies to encompass foundational literature in Human–Computer Interaction, neuroscience, and ergonomics. Secondly, we employ 'soft falsification' by actively seeking out and addressing theoretical tensions identified during the literature scoping phase. A primary example, which we elaborate upon in the subsequent theoretical framework, involves reconciling the historical divergence between Sensory Conflict and Postural Instability theories and addressing the paradox where technological affordances shift from 'enabling' to 'constraining'. The following section presents the development of the theoretical framework and shows how it can guide future empirical research on cybersickness in Metaverse travel.

5. Developing a theoretical framework for metaverse cybersickness

5.1. Affordance theory

Given the significant role of technology, we begin our conceptualisation through the lens of affordance theory. Similar to Cai et al. (2020), we propose using an affordance lens rather than examining individual features of the Metaverse, as affordances are often enabled or constrained by multiple features. Affordance theory, coined by Gibson (1977), suggests that the materials (in this context, technologies) inherently offer certain possibilities for action. Affordances focus on the relations between an individual and materials and emphasise the potential activities the individual can leverage enabled by the materials (McKenna, 2020). In technical contexts, the concept of affordances shifts the focus of human-centric technology use to human-artefact interaction (Zheng & Yu, 2016), which is instrumental in identifying previously overlooked non-human actors and the relational and contextual

Table 1. Affordance duality matrix.

Affordance Category	Affordance Description	Affordance Enabler or Constraint	Technical Mechanism & Observable Trace	Theoretical Interplay (Sensory Conflict & Postural Instability)
Spatial (e.g. Shin, 2022) [1]	The spatial design of virtual environments, including the layout, proportions, and spatial relationships between objects, should align with users' expectations and natural perceptions.	**Enabler**: Effortless movement across vast distances. **Constraint**: Instant transitions disrupt cognitive mapping.	**Mechanism**: Software. Teleportation or Continuous Steering. **Trace**: Frequent reorientation pauses; session aborts during high-speed travel.	**Sequential Link**: Violations of spatial affordances (e.g. visual motion without physical steps) trigger a Sensory Conflict between visual and vestibular systems (e.g. Oman, 1990). This mismatch subsequently impairs the body's ability to orient, leading to Postural Instability as the user struggles to maintain balance in unfamiliar spatial rhythms (Jung et al., 2021).
Temporal (e.g. Shin, 2022) [2]	The design of virtual environments should consider the temporal aspects of user interactions, such as the rate of scene transitions, animation speeds, and the synchronisation of visual and auditory cues.	**Enabler**: 'Always-on' engagement without schedule limits. **Constraint**: Lack of natural 'buffering periods' prevents sensory recovery.	**Mechanism**: Software. Continuous immersion loops; Latency/Lag. **Trace**: 'Micro-breaks'; decreased head movement over time.	**Feedback Loop:** Temporal distortions (e.g. lag or asynchronous cues) create immediate Sensory Conflicts (e.g. Draper et al., 2001). Prolonged exposure without breaks (a temporal constraint) fatigues the central nervous system, reducing its capacity to reweight sensory inputs, which culminates in Postural Instability over time (Lim et al., 2018; Weech et al., 2020).
Utilitarian & Embodiment (e.g. Shin, 2022) [3]	The design of interaction techniques should align with users' natural affordances for physical interactions, such as grasping, pushing, and navigating.	**Enabler**: Interactions that defy physical limitations (e.g. flying). **Constraint**: Disconnect between the visual force and the static body.	**Mechanism**: Hardware/software. 'Non-ecological mappings' (e.g. flying while sitting). **Trace**: Rigid posture ('comfort arms'); loss of balance.	**Primary Driver:** Postural Instability. While Sensory Conflict initiates the issue (visual acceleration vs. static vestibular cue), the primary manifestation here is Postural Instability (Riccio & Stoffregen, 1991). The body stiffens or sways because the 'unnatural' interaction disrupts the motor control required to maintain stability, often preceding nausea (Slater & Usoh, 1994)
Perceptual (Zhao et al., 2022) [4]	The visual design of virtual environments should consider perceptual affordances, such as depth cues, lighting, and colour contrasts, to create a coherent and natural-looking experience.	**Enabler**: Deep sense of presence via high-fidelity visuals. **Constraint**: Mismatches in focal depth trigger eyestrain.	**Mechanism**: Software. Binocular disparity; Motion-to-photon latency. **Trace**: Squinting; headset readjustment.	**Complementary Effect:** Inaccurate depth cues or lighting create a Sensory Conflict between the eyes and the user's expectations (LaViola, 2000). This forces the body to constantly micro-adjust posture to 'find' the correct horizon

(*Continued*)

Table 1. Continued.

Affordance Category	Affordance Description	Affordance Enabler or Constraint	Technical Mechanism & Observable Trace	Theoretical Interplay (Sensory Conflict & Postural Instability)
				or depth, creating a low-level Postural Instability that reinforces the feeling of sickness (Chung & Barnett-Cowan, 2023; Weech et al., 2020).
Multimodal (e.g. Zuo & Shen, 2024) [5]	The Metaverse should provide consistent, congruent affordances across multiple sensory modalities, including visual, auditory, and haptic feedback.	**Enabler**: Consistent immersion across senses. **Constraint**: Incongruent feedback breaks immersion.	**Mechanism**: Hardware/Software. Synchronisation of haptics/audio/video. **Trace**: Implied sensory confusion/ disorientation.	**Simultaneous Occurrence:** Incongruent inputs (e.g. seeing a crash but feeling no haptic impact) cause immediate Sensory Conflict (Reason & Brand, 1975). Because the body relies on multisensory integration for balance, this conflict simultaneously degrades Postural Stability, as the brain cannot determine the correct 'vertical' or 'stable' position (Bles et al., 1998; Josupeit & Andrees, 2024).

aspects between humans and technology (Majchrzak & Markus, 2012). Due to its unique emphasis, the same technology may offer different affordances depending on the user's relationship with it and the specific usage scenario and context (Chemero, 2003; Leonardi, 2013). While affordances often highlight the possibilities for action that technologies enable, the often-overlooked *constraints* they impose are equally significant. Constraints in the affordance theory refer to the other side of the coin of the 'enabling' – limitations and restrictions that technology imposes on possible actions (Norman, 1999). Most of the time, the enabler and the constraint come as a pair; this complexity provides a unique perspective for understanding Metaverse cybersickness.

Affordances can enable or constrain behaviour simultaneously. In the context of the Metaverse, constraints can arise from hardware limitations (e.g. restricted movement due to tethered headsets), software design choices (e.g. limited interaction options), or mismatches between virtual capabilities and physical realities. These material barriers might then affect some individuals' ability to perform expected actions or receive anticipated sensory feedback. However, this varies from individual to individual depending on their interaction history, physical abilities, and context. For example, travelling through a virtual location may induce cybersickness in some users, while others may be unaffected. Thus, affordances are enabling for some users and constraining for others, demonstrating the relational nature of affordance (the experiences can differ from person to person).

5.2. Cybersickness theories

To align the technological aspect with bodily responses, we further conceptualise our framework for studying Metaverse Cybersickness by combining two theories of cybersickness, *Sensory Conflict Theory* & *Postural Instability Theory* (LaViola, 2000), with affordance theory. Sensory Conflict Theory explains how constraints within technological affordances can lead to mismatches between visual, vestibular, and proprioceptive inputs, resulting in discomfort and nausea. Additionally, Postural Instability Theory suggests that these constraints impair the user's balance and stability, leading to cybersickness symptoms in virtual environments.

Sensory Conflict Theory proposes that sensory inputs from different modalities (e.g. visual, vestibular, and proprioceptive) must be consistent for an individual to experience a stable perception of motion and orientation. When these inputs are inconsistent or conflicting, it can lead to visually induced motion sickness (VIMS) (Bles et al., 1998; Reason, 1978). This theory suggests that the degree of sensory conflict determines the severity of motion sickness symptoms. Recent research has explored this theory through flight simulators (Kim et al., 2023), VR (Nam et al., 2022), and head-mounted displays (Park et al., 2022; Sato et al., 2022). As far as we can tell, this theory has not been used in tourism contexts.

Metaverse affordances can lead to sensory conflicts when they enable actions that produce visual motion without physical motion or vestibular cues. Commonly used affordances in the Metaverse, such as teleportation or rapid virtual movement, allow users to traverse virtual space swiftly, but the lack of physical motion leads to a sensory mismatch. In addition, constraints imposed by the equipment, such as a limited field of view or inadequate haptic feedback, prevent users from receiving complete sensory information, intensifying the conflict between senses. This conflict can trigger VIMS, leading to discomfort, nausea, and other adverse symptoms (Rebenitsch & Owen, 2016).

Postural Instability Theory suggests that motion sickness is caused by the body's inability to maintain postural stability when exposed to certain motion patterns or visual stimuli (Riccio & Stoffregen, 1991). This theory states that the body's central nervous system attempts to maintain postural stability by integrating sensory inputs from various sources; when these inputs conflict, this can lead to postural instability and motion sickness. Recent research has explored cybersickness in VR and head-mounted displays (e.g. Josupeit & Andrees, 2024; Teixeira et al., 2024). As far as we can tell, this theory has not been used in tourism contexts.

In Metaverse environments, affordances that enable novel body movements or perspectives, such as flying or inverted views, challenge the body's balance mechanisms. In addition, the absence of tactile and the mismatch between visual cues and the lack of corresponding physical motion or proprioceptive feedback disrupt the body's ability to maintain balance and posture, leading to motion sickness symptoms (Arcioni et al., 2019; Merhi et al., 2007).

Previous research has explored VR using both theories (Chen et al., 2022). Historically, Postural Instability Theory was proposed as an alternative and critique of Sensory Conflict Theory by arguing that it heavily relies on an individual's sensory history, and instead suggests the inability to maintain postural stability in an unfamiliar environment as the primary cause for cybersickness, shifting the focus from sensory mismatch to motor control and adaptation (Palmisano et al., 2020). Jung et al. (2021) argue that each theory has a different understanding of the primary causes of cybersickness: Sensory Conflict Theory posits that the conflict itself is the direct cause of sickness, while Postural Instability Theory argues that it is the inability to maintain postural stability (which may result from sensory conflict) that triggers symptoms.

Despite different focuses and understanding of the direct cause of sickness, we argue that sensory conflict and postural instability theories are complementary. Many studies found that sensory conflict increases cybersickness, and the postural instability often precedes or predicts sickness (Laessoe et al., 2023; Teixeira & Palmisano, 2021). Both theories are supported by evidence that the brain's ability to adapt or reweight sensory information is linked to cybersickness susceptibility, suggesting a shared underlying process (Chung & Barnett-Cowan, 2023). Several studies indicate a sequential relationship: affordance constraints lead to mismatches between sensory inputs and physical sensations (Sensory Conflict Theory), which in turn lead to postural instability, which then results in cybersickness symptoms (Jung et al., 2021; Weech et al., 2020). In practice, two processes may reinforce each other: sensory conflict can cause postural instability, and instability can heighten the effects of conflicts, creating a feedback loop (Lim et al., 2018; Weech et al., 2020).

5.3. A theoretical framework for cybersickness in metaverse travel

Our theoretical framework for cybersickness in Metaverse travel has two interconnected components. First, we develop an Affordance Duality in Metaverse Travel (Table 1) that synthesises

Metaverse tourism affordances with sensory conflict and postural instability theories. Second, we build on this matrix to propose a four-dimensional process model that organises cybersickness around virtual locomotion and bodily limits, time compression and sensory saturation, distinct pathways of cybersickness, and embodied inequalities in virtual mobility. Together, the matrix and the four-dimensional process constitute a single framework that links concrete Metaverse design features to patterned, embodied outcomes.

To illustrate the relationships among these three theories, their positioning within the enabling/constraining dynamics of affordance, and the temporal and sequential dimensions of the theoretical framework, we link the theories in Table 1. We synthesise affordance theory with these two theories, as it helps identify how certain design aspects lead to mismatches between sensory inputs and physical sensations, thereby impairing the user's ability to maintain balance. Incorporating affordance theory enriches the theoretical understanding of Metaverse cybersickness by adding a layer that explains how technological design influences physiological responses. It bridges the gap between the virtual environment's features and the user's physical experience. By combining these three theories, we can better understand Metaverse cybersickness as a relational, patterned outcome of specific design-body configurations. This approach extends affordance theory to consider embodied constraint and systematically accounts for how virtual tourism affects physiological responses.

When a user begins using the Metaverse, an affordance, or collection of affordances, enables the user to immerse themselves in the metaverse travel experience. For some users, affordances switch from enabling to constraining the experience sometime after using the Metaverse. Those same affordance(s) now cause the user to experience cybersickness. To further investigate this experience, a researcher should first consider the affordances that initially enabled it but then constrained it, leading to cybersickness. As affordances are relational between a user and a technology, sensory conflict theory and postural instability theory are used to understand the impact of cybersickness. We represent sensory conflict theory and postural instability theory as complementary and intertwined, as discussed earlier.

Table 1 presents an operationalised matrix that translates the theoretical concepts of affordance and cybersickness into a diagnostic tool. The table explicates the duality of Metaverse affordances across five distinct categories: Spatial, Temporal, Utilitarian & Embodiment, Perceptual, and Multimodal, their potential impact on cybersickness, and if these affordances are enabled or constrained by either the software (i.e. Metaverse systems and content) or the hardware (i.e. VR headsets) (Laessoe et al., 2023; Teixeira & Palmisano, 2021). Take 'Utilitarian and Embodiment' as an example: interaction techniques (e.g. grasping, pushing, navigating) first require the user to control them with a hardware device (perhaps a hand controller), which then requires the software affordance to react to those hardware inputs by visually displaying the act of grasping to the user. Therefore, there is a hardware affordance (user moves their hand) and a corresponding software affordance (visual representation of the hand grasping something). The table also illustrates the duality between enabling and constraining affordances in the Metaverse context, mapping functional affordance categories against their simultaneous effects. This is achieved by linking the Technical Mechanism (the design-level cause) with the Observable Traces (the measurable user behaviour) that lead to the constraints. The Theoretical Interplay column departs from the binary debate over whether Sensory Conflict or Postural Instability is the 'correct' theory; this table demonstrates that the physiological pathway to sickness is context-dependent based on the affordance type.

5.4. Four-dimensional process model

Building on Table 1's micro-level mapping, we further synthesise our arguments into a four-dimensional model that recomposes these elements into higher-order dynamics of virtual locomotion and bodily limits, time compression and sensory saturation, pathways of cybersickness, and embodied inequalities in virtual mobility, so that the table and model jointly form a theoretical framework for cybersickness in Metaverse travel.

5.4.1. Virtual locomotion and bodily limits[a]

The first dimension captures structural affordance asymmetry in Metaverse travel. Spatial affordances provide hypermobility, allowing tourists to teleport between scenes, change scale and perspective, or 'fly' to destinations (Christou & Aristidou, 2017). These affordances enable compelling virtual travel by decoupling visual motion from bodily motion (Oh & Son, 2022). The environment rapidly changes position and velocity, but vestibular and proprioceptive systems remain stationary (Oman, 1990). From a sensory conflict perspective, this asymmetry creates sustained conflict between visual and bodily cues, which then cascades into postural instability (Jung et al., 2021; Weech et al., 2020). Cybersickness is framed not as a malfunction, but as a predictable risk of designs that rely on asymmetric spatial affordances.

5.4.2. Compressed time and sensory saturation[b]

The second dimension concerns temporal saturation. Physical travel is structured by layered rhythms and buffers, allowing tourists to adjust between activities. In contrast, metaverse travel is organised around instant access and continuous immersion, compressing or eliminating transit and stacking experiences with few pauses (Harvey, 1999; Mogaji et al., 2023; Saleh, 2025). This configuration produces sensory saturation: prolonged exposure to rich audiovisual input and subtle postural effort leaves little time for recovery. This configuration is characterised by a feedback loop: as fatigue builds, the threshold for experiencing further conflict, such as nausea or dizziness, decreases (Lim et al., 2018), shortening the period during which many tourists can remain in the Metaverse environment. From Lefebvre's (2013) rhythmanalytical lens, Metaverse travel imposes a fast, programmable 'virtual rhythm' on bodies that still depend on slower biological rhythms of exertion and rest, resulting in arrhythmia.

5.4.3. Pathways of cybersickness[c]

The third dimension focuses on how cybersickness develops over time. The integration of affordances with sensory conflict and postural instability theory reveals distinct pathways rather than a single uniform trajectory. As summarised in the last column of Table 1, the exact theoretical mechanisms take different forms across affordance types: in some constellations, sensory conflict appears as an acute trigger, in others as a cumulative feedback process, while postural instability alternates between a downstream consequence and a primary driver. It is worth noting that the transition from enabling to constraining is not temporally fixed. The time it takes for an affordance configuration to shift from enjoyable to intolerable varies across individuals, depending on motion sickness history, prior VR use, gender, age, and the task being undertaken. It also depends on the display configuration, since head-mounted displays and flat screens differ in immersiveness and field of view, and thus in the intensity and timing of cybersickness onset (Terenzi & Zaal, 2020).

5.4.4. Embodied inequalities in virtual mobility[d]

The fourth dimension focuses on embodied inequalities: a hierarchy in which access to virtual mobility depends not only on having the proper hardware or bandwidth, but on the tolerance of one's vestibular and postural systems. At the top of this hierarchy, some tourists can tolerate high-friction environments with aggressive spatial, temporal, and multimodal affordances and experience only brief discomfort. At the bottom, others are quickly excluded when experiences require teleportation, rapid visual accelerations, prolonged immersion, or intense multimodal stimulation, especially when delivered through highly immersive head-mounted displays (Terenzi & Zaal, 2020). In such cases, the promise of frictionless Metaverse travel is effectively reserved for bodies with neurological tolerances. These patterns intersect with demographic differences in susceptibility, creating a biological digital divide. This divide constrains participation in Metaverse travel less by economics than by physiology. This fourth dimension highlights that cybersickness is both a design and a justice problem: addressing it requires not only technical mitigation but also critical attention to whose mobility is enabled, whose is constrained, and on what embodied terms.

5.5. Vignette

Here we illustrate our proposed theoretical framework with a hypothetical vignette. The numbers in the text link illustrate the affordances named in Table 1, and the letters link to each of the four dimensions from section 5.4.

Lisa, a 27-year-old experienced gamer, and Luke, a 46-year-old first-time user, log into a commercial Metaverse platform from home. They both put on VR headsets. Their avatars appear in a persistent 'World Hub', with portals, live visitor counts and friends' icons floating above a central plaza [4]. They both join a 'World Highlights' journey, visiting, six iconic environments in forty minutes [2].

They begin their journey over a coastal city. With a hand gesture, their avatars fly above the city [1]. Virtual forward motion and changes in altitude are smooth, while both their bodies remain seated in their physical locations [a, b]. Great detail, depth cues and a wide field of view allow them to fly over rooftops and water, reinforcing an effortless, shared hypermobility [4].

As the itinerary progresses, scene changes accelerate. The platform moves them from the city to a canyon, to a mountain village, and to a nighttime harbour, with only brief fade-outs and fade-ins between locations [2]. Lisa enjoys the experience. Luke notices that each new scene takes longer for his eyes to settle, and a dull discomfort collects behind his forehead. The absence of transit-like pauses prevents his system from recalibrating [2, b].

Midway through, the host AI invites participants to 'step into' selected scenes. On a glass platform over a gorge and a balcony above the harbour. Lisa tests how far she can edge towards the virtual drop while staying in control [3]. For Luke, the mismatch between strong visual cues of forward movement and the physical reality of sitting becomes uncomfortable. His torso and neck become increasingly tense as his body works to stabilise against incongruent visual and vestibular information [1].

In the final phase, the platform layers spatialised sound and low-frequency controller vibration as their avatars fly over a night skyline and along a cliff-lined coast [5]. For Lisa, the added sound and vibrations help anchor the illusion of movement; she ends the journey tired but comfortable. For Luke, earlier visual-vestibular conflict, accumulated temporal fatigue and intensified peripheral motion combine into a tipping point: nausea and light-headedness intensify over time [c]. He opens the in-world menu and leaves the session early.

Within a single Metaverse 'World Highlights' journey, the same configuration of spatial and navigational, temporal, embodiment, perceptual, and multimodal affordances, moves from enabling to constraining for Luke over a longer time frame, while Lisa felt very little discomfort throughout [a, b, c]. Lisa's experience illustrates how Metaverse affordances enable an enjoyable experience. Luke's illustrates how sequential triggers, temporal feedback and multimodal loading can culminate in cybersickness, leaving him unable to experience a journey for which both Lisa and Luke had equal technical access [d].

5.6. Applying the theoretical framework for future empirical work

Initially, the validity of this framework as conceptual research depends on its plausibility and coherence. However, to satisfy the requirement for empirical verification, future cross-disciplinary research must operationalise the 'traces' identified in Table 1. We propose that validation should move from this conceptual structure to empirical testing, where the predicted constraints are measured against the proposed affordance mechanisms in live tourist scenarios. Researchers should adopt 'soft falsification' (Xin et al., 2013), systematically seeking counter-evidence when high-fidelity affordances fail to trigger the predicted physiological constraints, thereby refining the framework's boundary conditions.

Additionally, future studies can implement cross-population investigation to understand how different user groups (e.g. age, cultural backgrounds, motion sickness history, levels of VR/Metaverse experience) interact with Metaverse affordances and experience cybersickness. Such studies can reveal whether the theoretical framework applies to diverse populations or needs adaptation to account for individual differences.

Furthermore, we encourage qualitative insights on affordance perception and embodied experience, particularly how users perceive and interpret Metaverse affordances and why certain affordances lead to cybersickness in some individuals but not others. Understanding these subjective experiences is crucial for refining the theoretical framework and enhancing its transferability. Longitudinal studies can examine how users' interactions with Metaverse affordances and their experiences of cybersickness change over time, offering insights into adaptation and tolerance development. Lastly, by applying the framework to develop design principles for Metaverse environments, researchers and designers can create virtual spaces that enhance positive experiences while mitigating those that lead to discomfort, minimising cybersickness, and improving overall user experience.

If Metaverse tourism becomes more commonplace, research into mitigating cybersickness is essential. Using the proposed theories and methodologies mentioned above, researchers could consider how to reduce the impact further. For example, the Metaverse should provide affordances for personalising the virtual environment to accommodate individual differences in sensory perception and user preferences. Mismatches in the affordances listed in Table 1, such as asynchronous visual and auditory cues, can create sensory conflicts that contribute to cybersickness. Personalisation could help to reduce cybersickness by tailoring the virtual experience to individual users' needs and capabilities. For example, in 2024, Apple announced new vehicle motion cues for iPhones, which can help reduce motion sickness. A similar approach could be tried with Metaverse travel to allow users to personalise their experience and prevent cybersickness.

Future research can also integrate methods that allow for the manipulation of sensory affordances (e.g. controlling visual speed or latency) alongside the precise, real-time measurement of the user's motor response. Specifically, researchers could use experimental designs (e.g. Bang et al., 2023; Varmaghani et al., 2022) to deliberately manipulate sensory inputs while simultaneously employing high-precision balance assessment tools to measure and analyse subjects' postural responses and stability (Teixeira et al., 2024). For further details of balance methods, refer to Teixeira et al. (2024) or Weech et al. (2018). An integrated approach is essential for distinguishing the different theoretical relationships between Sensory Conflict and Postural Instability, such as confirming a Sequential Cascade from a Simultaneous Collapse, and validating the context-dependent nature of cybersickness in Metaverse travel. Combining quantitative methods, e.g. physiological responses (Cowings et al., 1986), with qualitative assessments (e.g. interviews) would provide a comprehensive understanding of the underlying mechanisms, thus enabling researchers to align the bodily reactions to the affordances of the Metaverse.

6. Future outlook for cybersickness in metaverse travel

We must rethink Metaverse research away from proclamations of its disruptive impact, encouraging more critical and sceptical voices to examine the Metaverse in tourism. While this paper provides an overview of adverse physiological effects that can act as enablers or constraints, more research needs to consider the potential adverse emotional, mental health, and wellbeing impacts of its broader usage.

We consider many other areas where future research needs to examine how the potential benefits of these technologies can be realised inclusively for diverse populations. To date, solutions for the modalities of cybersickness mentioned earlier have not been presented. The Metaverse discourse currently consists primarily of advocacies from both industry and academia; however, several areas are overlooked. Firstly, tourists, the centre of the Metaverse, and their embodied experiences, are somehow neglected. Questions such as how our bodies feel when travelling in the Metaverse will need proper investigations. With the reconfigurations of time and space and the expected prolonged immersion in the virtual space, we need to shift the focus back to the relational aspect between Metaverse features and the users' embodied experiences and wellbeing. We thus call for a cross-disciplinary collaboration to critically investigate the phenomenon of cybersickness in Metaverse travel, including how time–space is constructed and experienced from a human geography perspective, physiological reactions from a neuroscience perspective, and the perception of presence and immersion from a cognitive psychology perspective.

Second, Metaverse sickness could potentially lead to a new digital divide (Reverte & Luque, 2021) between those who experience cybersickness and those who do not. **S**tudies have reported that 65% of users experience cybersickness symptoms in VR and approximately 24% experience severe symptoms (Garrido et al., 2022). Further, evidence suggests that age and gender can modulate cybersickness and presence, implying that HMD technology can systematically disadvantage some users, particularly on dimensions of age and gender (Yong et al., 2025). If destination experiences rely mostly on HMD devices, a significant segment of the population, by age and gender, will be excluded. This will create a new digital divide that can raise tensions within social groups, such as families, as some individuals are systematically excluded from virtual tourism experiences.

If more tourism providers adopt the Metaverse, issues arise in which those who cannot use it are excluded. Some Metaverse technologies may induce different levels of sickness, so tourist providers may need to consider different technologies or offer alternatives. A related issue is the potential negative impact on destination image due to cybersickness. If the Metaverse becomes the dominant means of accessing areas due to overtourism and environmental sensitivity concerns, induced cybersickness can create negative perceptions of the destination. A related issue is that these excluded customers may not be able to access the potential benefits of social interaction in the Metaverse.

Third, from a more practical aspect, the implementations of the Metaverse in tourism cannot take motions and mobilities out of the equation. When designing facilities and supporting equipment for the metaverse experience, the providers should consider how to reduce cybersickness induced by the sensory mismatch, postural instability, and the detachment between temporality and spatiality. In addition to improving the design, new health and safety protocols should be in place to provide warnings and support for users and, in the most extreme cases, address severe cybersickness.

Recent work argues that responsible Metaverse experiences should build in limits, pauses and 'reality exit points' to avoid drifting into a 'Darkverse' of overuse and health harms (e.g. Saleh, 2025). Time-bounded sessions and structured breaks directly counter sensory overload by re-introducing transit-like pauses in which sensory and postural systems can recalibrate, interrupting feedback loops of fatigue. Designing journeys that cycle between hypermobile segments and quieter, low-motion scenes can also reduce the strain created by virtual locomotion that exceeds bodily limits. In addition, framing 'frequent pauses' as a built-in feature rather than a purely individual choice acknowledges the embodied inequalities in virtual mobility.

Fourth, given its unique characteristics, we propose a more holistic approach to investigate cybersickness in Metaverse travel. This requires researchers to look at cybersickness beyond the sickness caused by sensory mismatch during the Metaverse trip, including the point of entry and after returning to the real world. The stark contrast between the stillness and mundaneness of everyday life and the often hypermobile, highly stimulating Metaverse virtual world is likely to make the stages of entry and withdrawal overwhelming and cause further sickness. A theoretical lens such as rhythmanalysis (Lefebvre, 2013) could provide a new perspective on how such drastic temporal and spatial shifts have affected an individual's internal rhythms and their long-term effects.

7. Conclusion

In this paper, we have made several contributions. Firstly, this study advances the understanding of motion sickness in travel by conceptualising it within the evolving landscape of travel technologies, specifically through the lens of cybersickness in Metaverse travel. We conceptualise motion sickness as a relational effect of technological affordances that shape embodied experiences, situating cybersickness as a product of intensified time–space compression and rhythm discords. By identifying key modes of cybersickness, including locomotion techniques, prolonged immersive experiences, and perceived intensified motion during virtual engagement, this research contributes to a new understanding of cybersickness in the context of Metaverse travel.

Second, we offered a deeper understanding of the often-overlooked constraint aspect of affordance theory and the nuanced dynamics between enabling and constraining affordances through a 'temporal paradox'. We challenge the static view of technology as purely 'enabling'. Our synthesis reveals a temporal paradox in Metaverse design: the high-fidelity immersion features (teleportation, continuous locomotion) that initially enable the tourism experience are precisely the mechanisms that, over time, transform into physiological constraints. This theoretical advancement contributes to affordance theory by demonstrating that 'constraints' are not just design flaws, but are often latent properties of 'enablers' that activate through prolonged human–computer interaction. The complexity of affordance contributes to the theoretical development of affordance theory in the sphere of IT and Tourism studies. Further, it contributes to the conversation of critical IT and Tourism studies. As researchers seeking to ensure inclusion in tourism, we need to further examine the potential harms of cybersickness as we embed technology into travel experiences.

Third, we develop a theoretical framework synthesising affordance theory, sensory conflict theory, and postural instability theory. This new theoretical framework provides a foundation for investigating cybersickness in Metaverse travel, with an emphasis on the relationships between Metaverse features and physiological reactions. Our framework illustrates the relationships between sensory conflict theory and postural instability theory, and how they can be used to understand changes in the balance between enabling and constraining affordances through a temporal perspective. We also present sensory conflict theory and postural instability theory as overlapping and sequential, demonstrating how they can contribute to cybersickness during metaverse travel. This framework offers a reflective synthesis that moves beyond treating cybersickness as merely a technical glitch. Instead, we posit it as a fundamental corporeal barrier embedded within the very design of virtual immersion.

Responding to calls for the critical turn in tourism studies (Ateljevic et al., 2007), this paper exposes cybersickness as a latent mechanism of digital inequality rather than a mere technical friction. We argue that the shift toward Metaverse tourism introduces a new power dynamic: a 'vestibular privilege', where the freedom of virtual movement is restricted to those with specific neurological tolerances. This creates a 'biological digital divide' that threatens to deepen existing social stratifications, particularly given evidence that susceptibility to cybersickness is disproportionately higher in women and older populations (Yildirim, 2024). Therefore, the uncritical promotion of the Metaverse as a universally accessible utopia becomes ethically problematic, as it masks the reality that these technological designs systematically exclude vulnerable bodies from participation. By situating physiological rejection within the broader discourse of the 'Darkverse' (Saleh, 2025; Singh et al., 2025), we demonstrate that digital exclusion is not just a matter of access to hardware, but of embodied accessibility (Small & Darcy, 2011), challenging the industry to recognise that technologies themselves carry political consequences (Winner, 2007) that can enforce a new hierarchy of mobilities.

This paper critiques the existing literature that frames the Metaverse as an almost frictionless extension of tourism. By spotlighting cybersickness, we offer a more diagnostic account of metaverse travel that attends to corporeal limits, discomfort and exclusion, rather than assuming that immersion is unproblematically enhancing. The framework is not intended to advocate for or against metaverse travel, but to help researchers and designers recognise sickness, withdrawal, and new forms of inaccessibility triggered by metaverse travel. Future work should examine whether metaverse-based experiences supplement, reconfigure, or merely simulate travel, and whether they should be conceptualised as 'travel' at all. We deliberately leave this as an open conceptual and empirical question, inviting cross-disciplinary collaboration to test, refine and contest the relationships proposed here.

Author contributions

CRediT: **Wenjie Cai:** Conceptualization, Formal analysis, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing; **Brad McKenna:** Conceptualization, Formal analysis, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing; **Nigel Williams:** Conceptualization, Validation, Writing – original draft, Writing – review & editing.

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