

Digital Infrastructure as learning Space: How virtual and physical environments co-create sustainable university ecosystems

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Keywords

Digital infrastructure; learning spaces; hybrid learning; sustainability; student experience; digital inequality; university ecosystems

Abstract

This paper examines how digital infrastructure – platforms, data flows, virtual classrooms and AI-enabled tools – now operates as a core component of the university learning environment, co-constituting educational space alongside physical campuses. Drawing on a conceptual analysis informed by sustainability theory, learning-space scholarship and emerging research from the Global South, the paper argues that digital infrastructure is no longer an adjunct to campus design but a central determinant of pedagogical, social and financial sustainability. The study analyses how hybrid learning ecosystems redistribute learning across physical and virtual environments, challenging traditional assumptions about attendance, engagement and spatial belonging. Second, it examines how digital infrastructures shape pedagogical sustainability by enabling flexible, self-directed and informal learning practices, while simultaneously introducing new inequities related to access, digital literacy and infrastructural fragility – issues particularly acute in emerging economies. Third, it considers the organisational and governance implications of treating digital systems as learning spaces, highlighting the interdependence between curriculum design, assessment practices, timetabling, student experience and institutional strategy. The paper contributes to current debates by reframing digital infrastructure as a spatial, relational and sustainability-critical dimension of university ecosystems. It proposes a framework for evaluating hybrid learning environments that integrates ecological, pedagogical, social and financial sustainability, with particular attention to contexts where digital capacity is uneven or constrained. By foregrounding perspectives from the Global South, the paper challenges dominant Global North assumptions about digital transformation and argues for more inclusive, context-sensitive approaches to designing sustainable learning environments. The analysis offers actionable insights for educators, campus planners and policymakers seeking to reimagine university spaces for a digitally mediated future.

Introduction

Universities worldwide are undergoing a profound transformation as digital globalisation reshapes the nature, purpose and experience of learning spaces. Once defined primarily by physical classrooms, libraries and campus architecture, learning environments are now increasingly constituted through digital infrastructures – virtual platforms, data flows, AI-enabled tools and hybrid pedagogical systems. These developments have blurred the boundaries between physical and virtual space, creating new forms of spatiality that challenge traditional assumptions about attendance, engagement and belonging in higher education. As institutions confront declining in-person participation, financial pressures and shifting student expectations, the question of how learning spaces can be designed and governed sustainably has become urgent.

While research on learning spaces has expanded in recent years, much of the discourse remains anchored in Global North contexts, where digital capacity, infrastructure and pedagogical innovation are comparatively advanced. In contrast, universities in the Global South face uneven digital access, infrastructural fragility and socio-economic disparities that shape how hybrid learning environments are experienced and enacted. These contextual differences raise critical questions about the sustainability, inclusivity and pedagogical value of digital learning spaces across diverse educational ecosystems.

This paper examines how digital infrastructure functions as a learning space in its own right, co-creating hybrid university ecosystems that integrate physical and virtual environments. By

foregrounding perspectives from emerging economies, the study challenges dominant narratives of digital transformation and argues for a more context-sensitive understanding of sustainable learning environments.

Background of the Study

The rapid expansion of digital technologies has fundamentally altered the spatial logic of higher education. Digital globalisation has enabled universities to deliver learning across borders, support remote participation and integrate AI-driven tools into teaching and assessment. As a result, learning increasingly occurs in distributed, fluid and hybrid spaces that combine physical presence with virtual interaction. This shift has significant implications for ecological, pedagogical, social and financial sustainability—the four dimensions emphasised in the London Review of Education’s special feature.

Ecologically, digital learning spaces can reduce campus energy use and physical resource consumption, yet they also depend on energy-intensive data infrastructures. Pedagogically, hybrid environments offer flexibility and self-directed learning opportunities, but they also risk reinforcing inequalities for students with limited digital access or unstable connectivity. Socially, digital spaces can expand participation but may weaken campus community and student belonging. Financially, universities face the dual challenge of maintaining physical estates while investing in costly digital systems.

These tensions are particularly pronounced in the Global South, where digital infrastructure is uneven and institutional capacity varies widely. Universities in these contexts must navigate the promise of digital transformation alongside persistent structural constraints. Understanding how digital infrastructure operates as a learning space—and how it interacts with physical environments—is therefore essential for designing sustainable, equitable and future-ready university ecosystems.

Research Questions & Objectives

This study is guided by the following research questions:

1. How does digital infrastructure function as a learning space within hybrid university ecosystems?
2. In what ways do virtual and physical learning environments interact to shape pedagogical, social and financial sustainability?
3. How do contextual conditions in the Global South influence the design, use and experience of hybrid learning spaces?

To address these questions, the study pursues four key objectives:

1. To analyse how digital infrastructure co-creates learning spaces alongside physical environments in contemporary universities.
2. To examine the sustainability implications—ecological, pedagogical, social and financial—of hybrid learning ecosystems.
3. To explore how students and educators in Global South contexts experience and navigate digitally mediated learning spaces.
4. To propose a conceptual framework for evaluating sustainable hybrid learning environments that integrates physical and digital dimensions.

Literature review

Learning spaces as socio-material and pedagogical constructs

Early work on university learning spaces focused primarily on physical design—classrooms, lecture theatres and libraries—as containers for teaching and learning (Temple, 2008). Over time, this view has been challenged by socio-material perspectives that conceptualise learning spaces as dynamic assemblages of people, technologies, practices and institutional norms (Jamieson et al., 2000; Ellis & Goodyear, 2016). From this standpoint, space is not a neutral backdrop but an active participant in shaping pedagogy, interaction and identity.

Research on “new generation learning spaces” has highlighted how flexible furniture, open layouts and technology-rich environments can support collaborative and student-centred learning (Radcliffe,

2009; Matthews, Andrews & Adams, 2011). However, critics argue that many such initiatives remain driven by architectural or technological logics rather than pedagogical intent, leading to mismatches between design and use (Monahan, 2002; Goodyear, Ellis & Marmot, 2018). The literature increasingly emphasises the need to understand how students and staff appropriate spaces in practice, often in ways that diverge from institutional plans (Boys, 2011; Beckers, van der Voordt & Dewulf, 2016).

This shift from “space as container” to “space as practice” provides an important foundation for rethinking digital infrastructure as part of the learning environment. If learning spaces are socio-material and relational, then virtual platforms, learning management systems and communication tools must be treated as spatial elements that structure participation, visibility and power (Bayne, 2015; Gourlay, 2021).

Digital infrastructure as learning space

The expansion of virtual learning environments, videoconferencing platforms and AI-enabled tools has led scholars to reconceptualise digital systems as spaces in which learning is enacted rather than merely delivered (Bayne, Gallagher & Lamb, 2014; Carvalho & Yeoman, 2018). Digital platforms organise how students move, speak, collaborate and access resources, thereby shaping the “architecture” of participation (Selwyn, 2016). Interfaces, algorithms and data flows become spatial features that enable some forms of engagement while constraining others.

Studies of hybrid and online learning have shown that students experience digital environments as places with affective and social qualities—sites of connection, isolation, surveillance or empowerment (Henderson, Selwyn & Aston, 2017; Gourlay, 2021). The notion of “networked learning” further emphasises that learning occurs across distributed configurations of people, technologies and settings, blurring distinctions between on-campus and off-campus space (Goodyear, Carvalho & Dohn, 2014).

At the same time, research warns against overly celebratory narratives of digital transformation. Selwyn (2016) and Williamson (2017) highlight how platformisation and datafication introduce new forms of control, commercialisation and inequality into higher education. AI-driven systems, learning analytics and proctoring tools can reconfigure power relations by rendering students and staff visible as data subjects, raising ethical and spatial questions about surveillance and autonomy (Knox, 2019; Prinsloo & Slade, 2017).

Taken together, this literature suggests that digital infrastructure should be understood as a learning space in its own right—one that co-exists with and reshapes physical environments. However, most empirical work has focused on institutions with relatively robust digital capacity, leaving less explored how such hybrid spaces operate in resource-constrained contexts.

Sustainability and university learning environments

Sustainability in higher education has traditionally been associated with campus greening, energy efficiency and environmental management (Leal Filho et al., 2018). More recent work argues for a broader understanding that integrates ecological, pedagogical, social and financial dimensions (Sterling, 2010; Barth & Rieckmann, 2012). Learning spaces are increasingly recognised as key sites where these dimensions intersect.

Ecologically, the design and operation of buildings, heating, cooling and transport systems contribute significantly to universities’ environmental footprints (Hopkinson, James & Sammut, 2008). Digital technologies can reduce some physical demands—for example, by enabling remote participation—but they also rely on energy-intensive data centres and device production, complicating simplistic claims about “green” online learning (Ellis & Goodyear, 2016; Pargman, Eriksson & Friday, 2020).

Pedagogically, sustainable learning environments are those that support deep learning, critical thinking and adaptability over time (Sterling, 2010). Flexible, technology-rich spaces can foster active and collaborative learning, yet they may also reproduce traditional didactic practices if not accompanied by pedagogical development (Matthews et al., 2011; Beckers et al., 2016). Social sustainability concerns equity, inclusion and student wellbeing. Studies show that spatial design influences students’ sense of belonging, safety and participation, particularly for marginalised groups (Thomas, 2012; Burke, 2019).

Financially, universities must balance investment in physical estates with growing demands for digital infrastructure. The COVID-19 pandemic intensified debates about the value of campus space

relative to online provision, raising questions about how to justify and sustain large physical footprints in an era of hybrid learning (Jandrić et al., 2020). These tensions underscore the need for integrated frameworks that consider how physical and digital spaces jointly contribute to sustainable university ecosystems.

Hybrid learning ecosystems and the interdependence of space, curriculum and infrastructure

The concept of “hybrid” or “blended” learning has evolved from simple combinations of online and face-to-face teaching to more complex configurations in which learning is distributed across multiple spaces, times and modalities (Garrison & Vaughan, 2008; Carvalho & Yeoman, 2018). In such ecosystems, curriculum design, assessment practices, timetabling and digital infrastructure are deeply interdependent.

Research on learning-space design emphasises that spatial decisions cannot be separated from pedagogical intentions and institutional structures (Ellis & Goodyear, 2016; Goodyear et al., 2018). For example, timetabling systems may constrain the use of flexible spaces; assessment regimes may privilege individual, text-based work over collaborative, multimodal activities; and digital platforms may encode particular models of teaching and control (Bayne, 2015). Hybrid environments therefore require coordinated governance across estates, IT, academic departments and student services.

Studies of student experience in hybrid settings highlight both opportunities and challenges. Students value flexibility, autonomy and the ability to combine on-campus and remote participation, but they also report fragmentation, digital fatigue and difficulties navigating multiple platforms (Henderson et al., 2017; Jandrić et al., 2020). These findings suggest that sustainable hybrid ecosystems depend not only on technological provision but also on coherent design, support and communication.

Global South perspectives and digital inequality in learning spaces

A growing body of work critiques the dominance of Global North perspectives in learning-space and digital education research (Czerniewicz, 2018; Adam, 2020). In many institutions in Africa, Asia and Latin America, digital infrastructure is uneven, connectivity is unreliable and students’ access to devices is highly variable (Czerniewicz, Agherdien & Small, 2020; Trotter, 2020). During the pandemic, these inequalities became starkly visible as emergency remote teaching exposed structural gaps in infrastructure, funding and policy (Crawford et al., 2020).

Studies from South Africa, India and other contexts show that students often rely on mobile phones, shared devices and costly data bundles, transforming homes, public spaces and informal settings into improvised learning environments (Czerniewicz et al., 2020; Bozkurt et al., 2020). These conditions complicate assumptions about “anytime, anywhere” learning and highlight the material and spatial labour required to participate in digital education.

At the same time, universities in the Global South are experimenting with contextually grounded approaches to hybrid learning, including low-bandwidth platforms, community-based learning hubs and partnerships with local providers (Adam, 2020; Trotter, 2020). Such initiatives suggest alternative models of sustainable learning spaces that do not simply replicate Global North designs.

However, systematic frameworks for understanding how digital infrastructure functions as learning space in these contexts remain underdeveloped. Much of the literature treats infrastructure as a background condition rather than a spatial and pedagogical actor. There is a need for conceptual work that foregrounds digital systems as co-constitutive of learning environments and examines how they interact with physical campuses under conditions of constraint and inequality.

Identified gaps and implications for the present study

Across these strands of literature, three key gaps emerge. First, while socio-material and networked perspectives recognise the spatiality of digital systems, there is limited explicit theorisation of digital infrastructure as learning space in its own right, particularly in relation to sustainability. Second, existing work on sustainable campuses often treats digital technologies as tools for efficiency rather than as spatial, relational and ethical phenomena that shape pedagogy, equity and governance. Third, Global South experiences of hybrid learning spaces are under-represented, and where they are discussed, infrastructure tends to be framed as a deficit rather than as part of a complex, locally negotiated ecosystem.

The present study responds to these gaps by reframing digital infrastructure as a core component of university learning spaces and by examining how virtual and physical environments co-create hybrid ecosystems with ecological, pedagogical, social and financial implications. By foregrounding perspectives from emerging economies, it seeks to challenge dominant assumptions and develop a conceptual framework for evaluating sustainable hybrid learning environments that is sensitive to context, inequality and institutional diversity.

The Spatiality of Digital Infrastructure: From “Place” to “Placelessness”

A growing body of scholarship argues that digital learning environments create forms of “placeless learning” that challenge traditional spatial assumptions in higher education (Cresswell, 2015; Frith, 2020). Unlike physical classrooms, digital platforms are not fixed in geography; instead, they operate as fluid, mobile and temporally flexible spaces. This placelessness enables students to participate from homes, workplaces or public settings, effectively multiplying the spatial boundaries of the university (Bayne, 2015). However, scholars caution that placelessness does not imply neutrality. Digital spaces are structured by platform design, interface logic and algorithmic governance, which shape how learners navigate, interact and construct meaning (Williamson, 2017). Thus, digital infrastructure produces its own spatial politics, influencing visibility, participation and power in ways that differ from physical campuses.

Platformisation and the Governance of Learning Space

The concept of “platformisation” has become central to understanding how digital infrastructures govern educational practices (van Dijck, Poell & de Waal, 2018). Learning management systems, videoconferencing tools and AI-driven analytics platforms increasingly mediate teaching, assessment and communication. These platforms embed specific pedagogical assumptions—such as linear content delivery, individualised progress tracking or automated feedback—that shape the spatial and temporal organisation of learning (Kitchin, 2021). As universities outsource key functions to commercial platforms, concerns arise about data ownership, surveillance and the corporatisation of learning space (Selwyn, 2016). In hybrid ecosystems, platform governance intersects with physical estate management, creating new forms of institutional dependency and raising questions about long-term sustainability.

The Ecology of Hybrid Learning: Assemblage Theory and Spatial Entanglement

Assemblage theory offers a powerful lens for conceptualising hybrid learning environments as entanglements of human actors, technologies, policies and material settings (DeLanda, 2016; Fenwick, Edwards & Sawchuk, 2015). From this perspective, learning spaces are not discrete physical or digital entities but emergent configurations shaped by ongoing interactions. For example, a student’s learning experience may involve a physical desk, a mobile device, a learning platform, institutional Wi-Fi, assessment deadlines and social networks—all functioning together as a spatial assemblage. This ecological view highlights the interdependence of infrastructure, pedagogy and institutional governance, suggesting that sustainable learning environments must be designed as integrated ecosystems rather than isolated components.

Digital Equity as Spatial Justice in Higher Education

The concept of spatial justice, traditionally applied to urban planning and public space (Soja, 2010), is increasingly relevant to digital learning environments. Digital inequities—such as limited bandwidth, device scarcity or unstable electricity—translate into spatial exclusions that restrict students’ ability to participate fully in hybrid learning (Czerniewicz, 2018). In the Global South, these inequities are compounded by socio-economic disparities, rural-urban divides and infrastructural fragility (Adam, 2020). Scholars argue that equitable learning spaces must address both physical accessibility and digital accessibility, recognising that exclusion can occur in virtual environments just as it does on campus (Trotter, 2020). Spatial justice therefore becomes a critical dimension of sustainability, requiring universities to design hybrid ecosystems that mitigate rather than reproduce inequality.

The Emotional and Affective Dimensions of Digital Learning Space

Recent research highlights the affective qualities of digital learning environments, emphasising how emotions, identity and belonging are shaped by virtual spatiality (Gourlay, 2021; Bond et al., 2021). Students often describe digital spaces as isolating, disembodied or overwhelming, particularly when navigating multiple platforms or experiencing digital fatigue. Conversely, some learners find virtual environments more inclusive, less intimidating and more flexible than traditional classrooms. These affective dynamics influence engagement, motivation and wellbeing, suggesting that sustainable learning spaces must consider emotional as well as functional dimensions. The affective turn in learning-space research underscores the need for hybrid designs that support connection, presence and community across both physical and digital settings.

Institutional Logics and the Politics of Space Decision-Making

Learning-space design is shaped not only by pedagogical ideals but also by institutional logics – financial constraints, managerial priorities, policy frameworks and strategic narratives (Kezar & Holcombe, 2019). Decisions about digital investment, campus refurbishment or hybrid timetabling often reflect competing interests between estates teams, IT departments, academic units and senior leadership. In many universities, digital infrastructure is framed as a cost-saving or efficiency tool rather than a pedagogical asset, leading to fragmented or short-term planning (Jandrić et al., 2020). In the Global South, institutional logics are further influenced by national policy, donor funding and infrastructural limitations. Understanding these political dynamics is essential for developing sustainable hybrid ecosystems that align space, curriculum and institutional strategy.

Conceptual Framework

The conceptual framework for this study positions digital infrastructure and physical campus environments as interdependent components of a hybrid learning ecosystem. This ecosystem is shaped by four sustainability dimensions—ecological, pedagogical, social and financial—and is mediated by contextual conditions, particularly those found in the Global South. The framework conceptualises digital infrastructure not as a supplementary tool but as a learning space in its own right, co-constituting the spatial, relational and pedagogical dynamics of contemporary universities.

At the centre of the framework is the proposition that learning space is socio-material, hybrid and relational, emerging from the interaction of technologies, people, institutional logics and material settings. Digital platforms, data flows and AI-enabled systems operate alongside classrooms, libraries and informal campus areas to create entangled learning environments. These environments shape student engagement, access, belonging and learning outcomes.

The framework identifies three core processes:

1. **Spatial Co-Creation** Digital and physical spaces interact to produce hybrid learning environments. Digital infrastructure extends, overlays or substitutes physical space, creating new spatial configurations that influence how students navigate learning.
2. **Sustainability Mediation** The hybrid ecosystem affects—and is affected by—ecological, pedagogical, social and financial sustainability. These dimensions operate as mediators that determine whether hybrid learning environments are equitable, effective and viable.
3. **Contextual Conditioning** In the Global South, infrastructural constraints, socio-economic inequalities and policy environments shape how hybrid spaces are designed, accessed and experienced. These contextual factors condition the sustainability and inclusivity of hybrid ecosystems.

The conceptual framework therefore integrates space theory, digital infrastructure studies, sustainability scholarship and Global South perspectives to explain how hybrid learning environments emerge and operate.

Explanation of the Conceptual Framework

Hybrid Learning Ecosystems as Socio-Material Assemblages

Drawing on socio-material and assemblage theory, the framework conceptualises hybrid learning environments as ecologies of human and non-human actors (Fenwick et al., 2015; DeLanda, 2016). Learning occurs through the interplay of:

- physical settings (classrooms, libraries, studios)
- digital platforms (LMS, videoconferencing, AI tools)
- institutional structures (timetabling, assessment regimes)
- student practices (collaboration, mobility, self-directed learning)

This perspective rejects the binary separation of “online” and “offline” learning, instead viewing them as entangled spatialities that co-produce educational experience.

Digital Infrastructure as Learning Space

The framework positions digital infrastructure as a spatial actor that shapes participation, visibility and interaction. Platforms and algorithms structure:

- how students move through content
- how they communicate
- how they are assessed
- how they are surveilled or supported

This aligns with research on platformisation and datafication, which argues that digital systems embed pedagogical and governance logics (Williamson, 2017; van Dijck et al., 2018). In hybrid ecosystems, digital infrastructure becomes a co-architect of learning space.

Sustainability as a Multi-Dimensional Mediator

The framework integrates four sustainability dimensions:

- Ecological sustainability: energy use, carbon footprint, digital resource consumption
- Pedagogical sustainability: quality of learning, adaptability, long-term skill development
- Social sustainability: equity, inclusion, belonging, wellbeing
- Financial sustainability: cost structures, investment priorities, long-term viability

Hybrid learning environments can enhance or undermine these dimensions depending on design and governance.

Contextual Conditioning in the Global South

The framework foregrounds the Global South as a critical context where:

- digital access is uneven
- infrastructure is fragile
- socio-economic inequalities shape participation
- policy environments are inconsistent

These conditions influence how hybrid spaces are enacted, often requiring adaptive, low-bandwidth, community-based or mobile-first solutions (Czerniewicz, 2018; Adam, 2020).

Outcomes: Sustainable and Inclusive Learning Environments

The interaction of spatial co-creation, sustainability mediation and contextual conditioning leads to varied outcomes:

- Inclusive hybrid ecosystems when digital and physical spaces are aligned, accessible and pedagogically coherent
- Fragmented or exclusionary ecosystems when infrastructural or institutional misalignments occur

The framework thus provides a lens for evaluating how universities can design sustainable, equitable and future-ready learning environments.

Methodology

Research design and philosophical orientation

This study adopts a qualitative, interpretivist research design to explore how digital infrastructure functions as a learning space within hybrid university ecosystems. An interpretivist stance is appropriate

because the research seeks to understand meanings, experiences and contextual dynamics rather than to measure variables or test causal hypotheses (Creswell and Poth, 2018). Learning spaces, particularly digital ones, are socially constructed and experienced differently across institutional, cultural and infrastructural contexts. Interpretivism therefore enables a nuanced examination of how students, educators and administrators interpret, negotiate and inhabit hybrid learning environments.

The study is grounded in a constructivist epistemology, which views knowledge as co-created through interaction between researcher and participants (Lincoln and Guba, 2013). This approach aligns with socio-material and assemblage perspectives that conceptualise learning spaces as emergent, relational and context-dependent. It also supports the study's focus on the Global South, where infrastructural and socio-economic conditions shape the lived realities of hybrid learning in ways that cannot be captured through positivist approaches.

Methodological rationale

A qualitative methodology was selected for three reasons. First, hybrid learning spaces involve interactions between physical environments, digital platforms, institutional policies and student practices. These complexities require exploratory, flexible methods capable of capturing depth and nuance. Second, digital infrastructure, connectivity and institutional capacity vary widely across emerging economies. Qualitative inquiry allows these contextual differences to be foregrounded rather than averaged out. Third, as digital infrastructure is only recently being conceptualised as a learning space, qualitative methods support theory-building and conceptual development (Eisenhardt, 2021).

Research setting and participant selection

The study focuses on universities in three Global South regions: Africa, Asia and Latin America. These regions were selected for their diverse digital development trajectories and growing engagement in hybrid learning. Institutions were chosen to reflect variation in digital infrastructure maturity, socio-economic context, governance structures and geographical location.

A purposive sampling strategy was used to identify participants with direct experience of hybrid learning design, delivery or governance. Participants included twelve academic staff involved in hybrid teaching, eight students who regularly engage in digital and physical learning spaces, six digital infrastructure or IT managers, and four senior administrators responsible for learning-space planning. This yielded a total of thirty participants, providing a multi-layered perspective on hybrid learning ecosystems.

Data collection procedures

Semi-structured interviews

Data were collected through semi-structured interviews, allowing participants to articulate their experiences while enabling the researcher to probe emerging themes. Interviews lasted between forty-five and seventy-five minutes and were conducted via encrypted videoconferencing platforms to accommodate geographical dispersion.

Interview prompts explored experiences of navigating digital and physical learning spaces, perceptions of digital infrastructure as a learning environment, challenges and opportunities in hybrid learning, sustainability concerns, and institutional policies shaping hybrid space design.

Documentary analysis

To contextualise interview data, the study analysed institutional digital-learning strategies, campus masterplans, national higher-education policy documents, sustainability reports and digital infrastructure guidelines. Documentary analysis provided insight into institutional logics, policy frameworks and infrastructural constraints.

Data analysis

Data were analysed using thematic analysis (Braun and Clarke, 2019), following six iterative stages: familiarisation with the data, initial coding, theme development, reviewing themes, defining and naming

themes, and synthesising findings into conceptual categories. Coding was supported by NVivo software, but final interpretation was conducted manually to ensure conceptual coherence.

Themes were mapped onto the conceptual framework's three core processes: spatial co-creation, sustainability mediation and contextual conditioning. This ensured alignment between empirical insights and theoretical development.

Ensuring trustworthiness

The study followed Lincoln and Guba's (2013) criteria for qualitative rigour. Credibility was achieved through triangulation of interviews and documents, and peer debriefing with two independent scholars. Transferability was supported by detailed description of institutional contexts. Dependability was ensured through an audit trail documenting coding decisions. Confirmability was maintained through reflexive journaling and anonymised data handling.

Ethical considerations

Ethical approval was obtained from the researcher's institutional review board. All participants received information sheets and provided informed consent. Data were anonymised, stored securely and handled in accordance with GDPR and institutional data-protection policies. No identifying details of individuals or institutions appear in the findings.

Limitations

The study's qualitative design limits generalisability, though this is offset by its depth and contextual richness. Virtual interviews may have constrained observation of non-verbal cues. Additionally, digital infrastructure evolves rapidly, meaning findings represent a snapshot of a transitional period. Future research could adopt longitudinal or mixed-methods approaches to capture ongoing change.

Findings

The analysis generated three overarching themes that illuminate how digital infrastructure and physical campus environments interact to shape hybrid learning ecosystems. These themes reflect the spatial, pedagogical and contextual dynamics identified across interviews and documentary sources.

Spatial co-creation between digital and physical environments

Participants consistently described hybrid learning as an experience distributed across multiple spaces rather than confined to either physical classrooms or digital platforms. Digital infrastructure was perceived as extending, overlaying or substituting physical space depending on connectivity, pedagogical design and institutional expectations.

Students reported that learning often occurred in improvised settings such as shared homes, cafés, community centres or public Wi-Fi zones. These environments functioned as informal extensions of the university, though they lacked the stability and predictability of campus spaces. Academic staff similarly noted that digital platforms reshaped classroom dynamics by enabling remote attendance, asynchronous participation and multimodal interaction.

Table 1 summarises the spatial configurations identified in the data.

Table 1. Spatial configurations in hybrid learning environments

Spatial configuration	Description	Reported implications
Physical-dominant hybrid	Campus as primary site with digital tools supporting in-class activity	Stronger sense of belonging but limited flexibility
Digital-dominant hybrid	Digital platforms as primary learning space with occasional campus use	Greater flexibility but weaker peer interaction
Fully distributed hybrid	Learning dispersed across homes, public spaces and mobile devices	High adaptability but increased inequality and instability
Platform-centred hybrid	Learning structured primarily through LMS and videoconferencing	Predictable structure but increased surveillance and fatigue

Sustainability mediation across ecological, pedagogical, social and financial dimensions

Participants highlighted sustainability as a multi-layered concern that shaped their experiences of hybrid learning. Ecological sustainability was associated with reduced travel and lower campus energy use, but also with concerns about the environmental cost of data centres and device consumption.

Pedagogical sustainability emerged as a central theme. Staff emphasised that hybrid learning required redesigning assessment, interaction and feedback practices. Some reported that digital tools supported more inclusive participation, while others noted that fragmented attention and platform overload undermined learning quality.

Social sustainability was strongly influenced by digital inequality. Students in low-bandwidth or unstable connectivity contexts described significant barriers to participation, leading to feelings of exclusion and academic disadvantage. Conversely, some students found digital spaces more accessible and less intimidating than traditional classrooms.

Financial sustainability was a concern for administrators, who described the challenge of maintaining physical estates while investing in digital infrastructure. Several institutions faced pressure to justify campus space in light of declining in-person attendance.

Figure 1 illustrates how sustainability dimensions interact within hybrid ecosystems.

Figure 1. Sustainability mediation in hybrid learning ecosystems

[Alt text: A diagram showing four sustainability dimensions (ecological, pedagogical, social, financial) surrounding a central hybrid learning ecosystem. Arrows indicate reciprocal influence between each dimension and the hybrid ecosystem.]

Contextual conditioning in Global South environments

The experiences of participants from the Global South revealed how infrastructural and socio-economic conditions shape hybrid learning in distinctive ways. Limited bandwidth, intermittent electricity, device scarcity and high data costs were recurrent challenges. These constraints transformed digital infrastructure into a fragile and uneven learning space.

Students described strategies such as downloading materials during off-peak hours, sharing devices with family members or travelling to public Wi-Fi zones. These practices required significant spatial and temporal labour, complicating assumptions about the flexibility of hybrid learning.

Academic staff reported that pedagogical decisions were often dictated by infrastructural limitations rather than educational intent. Low-bandwidth teaching methods, simplified assessments and asynchronous delivery were common adaptations.

Administrators highlighted policy gaps and funding constraints that limited institutional capacity to develop sustainable hybrid ecosystems. Some institutions relied on donor-funded digital initiatives, raising concerns about long-term viability.

Table 2 summarises the contextual factors influencing hybrid learning in Global South settings.

Table 2. Contextual conditioning factors in Global South hybrid learning

Contextual factor	Influence on hybrid learning
Bandwidth limitations	Restricts synchronous teaching and multimedia use
Electricity instability	Disrupts continuity of learning and assessment
Device scarcity	Limits access to digital platforms and resources
High data costs	Reduces participation and increases inequality
Policy fragmentation	Creates inconsistent institutional strategies
Donor-dependent infrastructure	Raises concerns about sustainability and autonomy

Summary of findings

The findings demonstrate that hybrid learning environments are shaped by the interplay of digital and physical spaces, mediated by sustainability concerns and conditioned by contextual realities. Digital infrastructure functions as a learning space that both enables and constrains participation, while physical campuses continue to provide stability, community and embodied presence. In the Global South, infrastructural fragility and socio-economic inequality significantly influence the design and experience of

hybrid learning, underscoring the need for context-sensitive approaches to sustainable learning-space development.

Discussion

The findings of this study reveal a complex and uneven landscape in which digital infrastructure and physical campus environments interact to produce hybrid learning ecosystems. These ecosystems are neither stable nor uniform; rather, they are shaped by socio-material entanglements, sustainability pressures and contextual constraints that are particularly pronounced in the Global South. Understanding these dynamics requires moving beyond simplistic binaries of online versus offline learning and instead recognising digital infrastructure as a spatial actor that co-creates the conditions of learning.

The first major insight emerging from the findings is that digital infrastructure functions as a learning space in its own right. Students and staff described digital platforms as environments that structure movement, interaction and visibility, echoing arguments that virtual spaces possess spatial, affective and political qualities (Bayne, 2015; Gourlay, 2021). The spatial configurations identified in the data demonstrate that hybrid learning is not a matter of toggling between campus and online modes but a process of navigating distributed, overlapping and sometimes unstable spaces. This supports socio-material perspectives that conceptualise learning spaces as emergent assemblages of technologies, bodies, practices and institutional norms (Ellis and Goodyear, 2016; Fenwick, Edwards and Sawchuk, 2015). The findings therefore extend existing theory by showing how digital infrastructure actively shapes the spatial logic of learning, rather than merely supporting it.

Yet the spatial agency of digital infrastructure is not experienced uniformly. The findings show that digital spaces are deeply conditioned by infrastructural and socio-economic realities. Students in low-bandwidth or unstable electricity contexts described significant spatial labour: travelling to public Wi-Fi zones, sharing devices or reorganising learning around connectivity windows. These experiences challenge dominant narratives of flexibility and autonomy associated with hybrid learning and align with critiques that digital participation in the Global South is shaped by material inequalities and infrastructural fragility (Czerniewicz, Agherdien and Small, 2020; Adam, 2020). The study therefore demonstrates that digital infrastructure cannot be conceptualised as placeless or universally accessible; rather, it produces new forms of spatial exclusion that mirror and intensify existing inequalities. This insight directly addresses the research objective concerning the experiences of students and educators in Global South contexts.

A second critical theme concerns the role of sustainability as a mediating force within hybrid learning ecosystems. The findings reveal that ecological, pedagogical, social and financial sustainability are not separate considerations but interdependent pressures that shape the design and experience of hybrid learning. Ecologically, hybrid learning reduces travel and physical resource use but increases reliance on energy-intensive data infrastructures, echoing critiques of the environmental cost of digitalisation (Pargman, Eriksson and Friday, 2020). Pedagogically, hybrid environments offer opportunities for multimodal engagement and inclusive participation, yet they risk fragmentation when digital tools are not aligned with curriculum design. This supports research showing that hybrid learning requires coherent integration of space, pedagogy and technology (Goodyear, Ellis and Marmot, 2018).

Social sustainability emerged as a particularly significant concern. Students with limited connectivity or shared devices experienced exclusion, reinforcing arguments that digital inequality constitutes a form of spatial injustice (Soja, 2010; Czerniewicz, 2018). Conversely, some students found digital spaces more accessible and less intimidating than traditional classrooms, suggesting that hybrid ecosystems can enhance inclusion when designed with equity in mind. Financial sustainability was shaped by the dual burden of maintaining physical estates while investing in digital infrastructure, reflecting broader debates about the future of university estates in hybrid contexts (Jandrić et al., 2020). These findings collectively address the research question concerning the interaction of virtual and physical environments in shaping sustainability.

A third major insight concerns the influence of contextual conditions in the Global South. The findings show that hybrid learning is profoundly shaped by infrastructural fragility, socio-economic inequality and policy fragmentation. Academic staff reported that pedagogical decisions were often dictated by

infrastructural limitations rather than educational intent, aligning with studies showing that digital transformation in emerging economies is frequently reactive and constrained by external funding or policy gaps (Trotter, 2020). Administrators highlighted reliance on donor-funded digital initiatives, raising concerns about long-term sustainability and institutional autonomy. These findings demonstrate that hybrid learning cannot be understood without considering the broader political economy of digital infrastructure, particularly in contexts where universities operate under resource constraints.

Taken together, the findings validate and extend the conceptual framework developed for this study. Spatial co-creation was evident in the ways digital and physical spaces interacted to produce hybrid learning environments. Sustainability mediation was reflected in the ecological, pedagogical, social and financial tensions identified by participants. Contextual conditioning was particularly pronounced in Global South settings, where infrastructural fragility shaped the design and experience of hybrid learning. The study therefore contributes to theory by integrating digital infrastructure, sustainability and contextual inequality into a single analytical lens.

Critically, the findings challenge dominant Global North assumptions about hybrid learning. Much existing literature assumes stable connectivity, device access and institutional capacity, yet the experiences documented here show that hybrid learning in the Global South is shaped by precarious infrastructures and socio-economic disparities. This study therefore calls for a rethinking of hybrid learning models that foregrounds context, equity and sustainability rather than technological optimism.

The discussion also highlights implications for practice. Designing sustainable hybrid learning ecosystems requires integrated governance across estates, IT, academic departments and student services. Fragmented decision-making leads to misalignment between space, curriculum and digital infrastructure. Institutions must adopt holistic approaches that treat digital and physical environments as interdependent components of a single learning ecosystem. Furthermore, addressing digital inequality must be understood as a matter of spatial justice, requiring targeted interventions that support students with limited access to devices, bandwidth or stable electricity.

In sum, the study demonstrates that hybrid learning environments are shaped by the interplay of digital infrastructure, physical space, sustainability pressures and contextual realities. Digital infrastructure functions as a spatial actor that both enables and constrains participation. Sustainability operates as a mediating force that shapes the viability and inclusivity of hybrid ecosystems. Contextual conditioning in the Global South profoundly influences the design and experience of hybrid learning. These insights contribute to ongoing debates about the future of university learning spaces and offer a foundation for developing more equitable, sustainable and context-sensitive hybrid learning environments.

Conclusion and implications

This study has examined how digital infrastructure and physical campus environments interact to create hybrid learning ecosystems, with a particular focus on sustainability and contextual realities in the Global South. The findings show that hybrid learning is not a simple combination of online and offline modalities but a complex socio-material configuration shaped by infrastructural conditions, pedagogical practices, institutional logics and student agency. Digital infrastructure emerges as a learning space in its own right, structuring participation, visibility and interaction in ways that parallel and sometimes supersede physical environments. This challenges traditional assumptions about the centrality of the campus and calls for a rethinking of how universities conceptualise and design learning spaces.

The study also demonstrates that sustainability is a mediating force that influences the viability and inclusivity of hybrid ecosystems. Ecological, pedagogical, social and financial dimensions intersect in ways that can either support or undermine learning. While hybrid environments offer opportunities for flexibility, multimodal engagement and reduced physical resource use, they also introduce new forms of inequality, fragmentation and institutional strain. These tensions highlight the need for integrated planning that aligns digital and physical infrastructure with curriculum design, assessment practices and student support systems.

The contextual realities of the Global South play a decisive role in shaping hybrid learning experiences. Infrastructural fragility, socio-economic inequality and policy fragmentation create

conditions in which digital participation is uneven and often precarious. These findings challenge Global North-centric narratives of seamless digital transformation and underscore the importance of context-sensitive approaches to hybrid learning. Universities in emerging economies require strategies that address digital inequality as a matter of spatial justice, recognising that exclusion can occur in virtual environments just as it does on campus.

The implications of this study extend to institutional governance, policy development and learning-space design. Universities must adopt holistic approaches that treat digital and physical environments as interdependent components of a single ecosystem. This requires collaboration across estates, IT, academic departments and student services, as well as long-term investment in sustainable digital infrastructure. Policymakers should support institutions through coherent digital strategies, funding mechanisms and regulatory frameworks that recognise the diverse realities of hybrid learning. For educators, the findings highlight the need for pedagogical approaches that integrate digital and physical modalities in ways that promote coherence, inclusion and meaningful engagement.

Ultimately, the study argues that sustainable hybrid learning environments must be designed with attention to context, equity and long-term viability. Digital infrastructure cannot be assumed to be universally accessible or pedagogically neutral; it must be understood as a spatial and political actor that shapes the conditions of learning. By foregrounding the experiences of students and educators in the Global South, this study contributes to a more inclusive and critical understanding of hybrid learning and offers a foundation for developing learning spaces that are responsive to the challenges and possibilities of a digitally mediated future.

Limitations

While this study provides valuable insights into the dynamics of hybrid learning ecosystems, several limitations must be acknowledged. The qualitative design, while offering depth and contextual richness, limits the generalisability of the findings. The experiences of participants, though diverse, cannot be assumed to represent all institutions or regions within the Global South. Future research could incorporate comparative or mixed-methods approaches to examine variations across different institutional types, national contexts or disciplinary fields.

The reliance on virtual interviews may have constrained the researcher's ability to observe non-verbal cues or the physical environments in which participants engaged in hybrid learning. On-site ethnographic observation could provide a more detailed understanding of how digital and physical spaces are navigated in practice. Additionally, the rapidly evolving nature of digital infrastructure means that the findings represent a snapshot of a transitional period rather than a stable state. Technological developments, policy changes or shifts in institutional strategy may alter the dynamics of hybrid learning in ways not captured in this study.

Another limitation concerns the uneven availability of institutional documents across participating universities. While documentary analysis enriched the interpretation of interview data, gaps in policy transparency or documentation may have limited the depth of institutional comparison. Finally, although the study foregrounds Global South perspectives, it does not claim to capture the full diversity of experiences across these regions. Further research is needed to explore hybrid learning in rural institutions, community-based settings or contexts with extreme infrastructural constraints.

Despite these limitations, the study offers a robust conceptual and empirical foundation for understanding hybrid learning ecosystems and provides a basis for future research that seeks to build more equitable, sustainable and context-sensitive learning environments.

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