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The future workplace: developing the human-machine symbioscape

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Abstract

Purpose – This paper develops the concept of the human-machine symbioscape to explain how work environments shape collaboration between humans and AI-enabled machines. Extending servicescape thinking from customer-employee encounters to hybrid human-machine work systems, the paper positions environmental design as a core antecedent of human–machine adaptive collaboration, with particular relevance for service and frontline settings where visibility, coordination, and role clarity are critical.

Design/methodology/approach – The paper is conceptual and theory building in nature. It synthesises insights from biological symbiosis, servicescape research, sociotechnical and sociomaterial theory, organisational sensemaking and team adaptation research to develop a deductive typology of the human-machine symbioscape as a three-tiered environmental construct, its cue categories, and its design-critical properties. The framework is further illustrated through a structured coding of relevant human-machine collaboration studies.

Findings – The paper conceptualises the symbioscape as a three-tier environmental architecture comprising physical–digital, socio-relational, and institutional–ecosystem conditions. Across these tiers, six cue categories shape what human and AI-enabled actors can notice, how they coordinate work, and how collaborative routines are reinforced over time. Drawing on Weick's sensemaking theory, the framework links these tiers to enactment, selection, and retention processes, and explains how they influence adaptation speed, adaptation effectiveness, and adaptation persistence in human–AI collaboration.

Research limitations/implications – The paper is purely conceptual and does not empirically test the proposed relationships. Its evidence base is limited to published studies and illustrative coding, with a strong emphasis on service and frontline contexts. It identifies an agenda for future research around operationalising symbioscape constructs, testing the proposed relationships empirically, and examining how individual tiers and cross-tier configurations jointly affect human–machine work.

Practical implications – The symbioscape framework provides managers with a structured lens for designing AI-enabled workplaces. It highlights how deliberate choices in physical–digital visibility and interface design, socio-relational workflow sequencing and interaction load, and institutional governance, training, and role architecture can improve the speed, quality and durability of human–machine adaptation. The framework can be used to diagnose service work environments, where frontline employees must coordinate with intelligent systems under conditions of customer presence, temporal pressure, and operational variability.

Originality/value – The paper introduces the symbioscape as a novel, three-tier environmental construct for human–machine collaboration, extending the servicescape from customer–employee encounters to hybrid human–AI work systems. It adds a missing environmental layer to human-machine collaboration research by

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systematically integrating dispersed insights on context into a coherent framework that links environmental cue structures to sensemaking and adaptation outcomes. For scholars, it offers an integrative conceptual architecture; for practitioners, it provides a foundation for designing and structuring future workplaces that foster adaptive human–machine collaboration.

Keywords Human-machine collaboration, Symbioscape, Servicescape, Sensemaking, AI-enabled workplaces
Paper type Conceptual paper

> According to Darwin's Origin of Species, it is not the most intellectual of the species that survives; it is not the strongest that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself. —Leon C. Megginson (1963), quoted in Darwin Correspondence Project (2016).

Introduction

Humans and machines increasingly work together to address complex challenges in the age of pervasive automation and artificial intelligence (Seeber *et al.*, 2020; Krafft *et al.*, 2020; Kunz *et al.*, 2025). Across industries, intelligent agents now participate in decision-making, coordination, and frontline service encounters, creating hybrid work systems in which human and machine contributions are tightly interwoven. For example, Klarna's AI agent handles customer interactions and operational decisions, while humans address ambiguity, escalation and exceptions, demonstrating the growing interdependence of machine execution and human judgement (Kelly, 2024). Although research on human–machine collaboration and human–AI teaming has expanded rapidly (e.g. Noble *et al.*, 2022; Huang and Rust, 2018; Le *et al.*, 2023, 2025), existing frameworks have focused primarily on how collaboration is distributed across actors, through task allocation, capability matching, and interdependence. Researchers have only recently begun to pay attention to the environmental conditions under which such collaborations unfold (Van Riel *et al.*, 2025).

This gap is striking in service settings, because service work is often customer-facing, emotionally demanding, and occurs under time pressure. This is especially important because employees must often decide when to rely on AI or robots for routine and data-based requests and when to step in themselves to manage uncertainty, guest emotion, and service recovery. Frontline employees must coordinate not only with technologies, but also with customers, colleagues and organisational rules under conditions of uncertainty. In such settings, collaboration depends not only on the technologies and their functionalities, but also on the working conditions. An environmental perspective is therefore particularly important to understand how human-machine collaboration becomes effective across all service sectors.

Environments have long been recognised as central to shaping experience and performance. In marketing, early notions of atmospherics (Kotler, 1973) and the servicescape (Bitner, 1992) established how physical surroundings influence both customer behaviour and employee outcomes. Later work extended these ideas to employee experience (Kearney *et al.*, 2023), organisational design (Hall, 2008), and workplace interaction patterns (Brown *et al.*, 2014). Yet these perspectives have not been systematically connected to human–machine collaboration, even though such environments determine which cues are available for interpretation, how actors coordinate, and how they adapt to one another in real time. Extending environmental theorising to human–machine collaboration therefore helps explain how workplace conditions shape the quality, viability, and sustainability of hybrid work.

To address this oversight, we introduce the concept of the *symbioscape*, a term derived from the biological notion of symbiosis. Biological symbiosis refers to the coexistence and co-adaptation of two dissimilar organisms in shared environments through continuous sensing, feedback, and interaction (Apprill, 2020), an idea that has been adapted to human–machine symbiosis (Inga *et al.*, 2023; Licklider, 1960). In this research, we adapt symbiosis as an environmental lens by shifting attention from biological co-existence between species to the shared conditions under which humans and AI-enabled machines interact, coordinate,

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and adapt over time. Building on this, we define the human-machine symbioscape as the physical–digital, socio-relational, and institutional-ecosystem cues that constitute the collaborative work environment of human-AI work.

The symbioscape complements and extends the servicescape by shifting the focus from customer–employee encounters to hybrid work systems in which humans and AI-enabled agents collaborate. It captures not only material and spatial conditions, but also digital interfaces, temporal interaction structures, governance arrangements, and role architectures. These environmental cues matter because they shape what humans and machines can notice, how they coordinate joint activity, and whether new patterns of collaboration become stabilised over time. In this sense, the symbioscape is not simply another label for sociotechnical context, but a layered environmental cue architecture through which collaborative work becomes perceptible, coordinated, and reinforced in practice.

Despite the growing importance of such work conditions, the environmental dimension of human–machine collaboration has not been systematically theorised. Existing models highlight complementarities between human and machine capabilities (Huang and Rust, 2021), task interdependencies (Le *et al.*, 2023), or collaborative intelligence (Wilson and Daugherty, 2018), but rarely address how work environments shape the possibility, speed, quality, and persistence of adaptation. As a result, we still know little about which environmental cues, such as interface visibility, workflow sequencing, monitoring burden, and governance arrangements, are most critical for enabling effective human–machine collaboration and therefore require deliberate workplace design.

This paper develops the concept of the symbioscape to address this gap. By drawing on an integrative synthesis of biological symbiosis, servicescape research, sociotechnical and sociomaterial theory, organisational sensemaking, and team adaptation research, we develop a deductive typology of the collaborative work environment. We identify three tiers (physical–digital, socio-relational, and institutional-ecosystem) of environmental influence and specify the cue categories and design-critical cue properties through which each tier shapes human–machine collaboration. We then link these environmental conditions to Weick's (1979, 1995) sensemaking processes of enactment, selection and retention in order to explain how workplace environments shape adaptation speed, adaptation effectiveness, and adaptation persistence in human-machine work.

The distinct value of the symbioscape lies in specifying what existing sociotechnical, sociomaterial, service automation, and human–AI collaboration frameworks tend to leave underspecified, namely, the environmental cue architecture through which human–machine collaboration becomes visible, coordinated, and retained. Existing frameworks often focus on the actors, roles, capabilities, and relationships involved in human–machine collaboration but pay less attention to the environmental cues that make those relationships workable in practice. Sociotechnical and sociomaterial perspectives establish that work is configured through relations among people, technologies, and organisational arrangements, but they do not specify which cue families in the work environment shape different forms of adaptation. Servicescape research explains how environments shape service experience, but it has not been extended to hybrid human–AI work systems. The symbioscape integrates these insights by explaining why similar AI systems may produce different adaptive outcomes depending on whether physical–digital cues support noticing, socio-relational cues support coordinated response selection, and institutional–ecosystem cues support retention.

This article makes three main contributions. *First*, it introduces the concept of the *symbioscape* as a three-tier environmental construct that extends servicescape thinking from customer–employee encounters to hybrid human–machine work systems. *Second*, it adds a missing environmental layer to human–machine collaboration research by theorising how specific environmental cues and cue properties shape joint work and adaptation in human–machine teams (Le *et al.*, 2025; Kunz *et al.*, 2025; Sajtos *et al.*, 2024). *Third*, by drawing on team adaptation and organisational sensemaking, we develop a symbioscape–mechanism–adaptation framework that links each tier of the symbioscape to distinct yet interrelated forms

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of adaptive response. Together, these contributions reposition the work environment as an active infrastructure of human–machine collaboration and provide a conceptual foundation for designing future workplaces that foster adaptive and sustainable human–machine teams.

Developing the concept of symbioscape

In marketing, the *servicescape* literature explains how environments shape experience and behaviour during service encounters. Kotler's (1973) work on atmospherics emphasised the influence of environmental stimuli, and Bitner (1992) formalised these ideas by defining the servicescape as the built, physical, and social setting in which service interactions occur. Drawing from environmental and ecological psychology (Bell *et al.*, 1978; Stokols, 1977), Bitner (1992) identified three foundational dimensions through which environments influence how people think, feel, and act: ambient conditions, spatial layout and functionality, and signs, symbols, and artefacts. Although originally theorised around customer experiences in customer–employee encounters, subsequent work expanded the framework beyond the physical domain to include social, symbolic, and natural elements, emphasising that service experiences are co-constructed through material and interpersonal conditions and shared meanings across touchpoints (Rosenbaum and Massiah, 2011; De Keyser *et al.*, 2019). Furthermore, the servicescape perspective has been extended to employee work, showing how workspace conditions, tools, layout, workflow design, and team climates shape employee experiences and service outcomes (Homburg and Stock, 2004; Bowen and Schneider, 2014; Kearney *et al.*, 2023). Taken together, the servicescape and employee servicescape literature motivate a tiered way of thinking about environments. One tier concerns physical conditions, layout, and artefacts that shape perception and movement. A second tier concerns social and relational conditions that structure interaction and coordination. A third tier concerns institutional and ecosystem-level meanings and arrangements, such as norms, role structures, standards, and governance, that stabilise expectations and reinforce legitimate practice.

This three-tiered view also aligns with sociotechnical and sociomaterial perspectives that treat work as an accomplishment of configurations rather than a simple function of people or technology alone. Sociotechnical systems research argues that performance depends on the joint optimisation and ongoing fit between the technical subsystem and the social organisation of work (Trist and Bamforth, 1951). Sociomaterial research similarly emphasises that technologies do not merely sit within contexts but participate in practices by shaping what becomes visible, actionable, and accountable in everyday activity (Orlikowski, 2007). These perspectives support an environmental view in which collaboration is enabled or constrained by the cues a setting makes available, the interaction patterns it affords, and the institutional arrangements it reinforces.

This environmental lens becomes especially relevant as artificial intelligence and robotics become embedded in work settings, particularly in service settings, where employees must coordinate with algorithmic and robotic agents under conditions of customer presence, temporal pressure, variability, and interruption. In such settings, human–machine collaboration relies not only on complementary capabilities or task allocation, but also on whether relevant states, handovers, responsibilities and constraints are legible at the point of action. Environments therefore do more than surround work; they shape what is noticed, how work is sequenced, and how coordination is performed as activity moves between human and machine contributors.

The biological concept of symbiosis provides a second foundation for developing our environmental perspective. Symbiosis describes sustained coexistence and co-adaptation between dissimilar organisms through continuous sensing, feedback, and interaction within a shared environment (de Bary, 1879; Moran, 2007; Apprill, 2020). In contrast to the Darwinian, purely competitive view of adaptation, symbiosis highlights how dissimilar entities evolve together by developing new capacities through repeated interactions in a common habitat (de Bary, 1879; Moran, 2007; Paracer and Ahmadjian, 2000; Oliver and Russell, 2016; Apprill, 2020). Symbiotic

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systems vary in outcome patterns, ranging from mutualism (both species benefit) to commensalism (one species benefits, the other is unaffected) and parasitism (one species benefits, the other is harmed), and also vary in the degree of dependency between partners, such as whether the relationship is obligate (necessity of co-habitation) or facultative (optional co-habitation) (Apprill, 2020). For the present purpose, the central insight is not the taxonomy of relationship types but the premise that adaptation emerges through repeated interaction that is enabled (making collaboration possible), channelled (shaping how collaboration unfolds), and stabilised (helping recurring patterns to persist) by the surrounding environment. In line with this view, Inga *et al.* (2023) argue that human–machine symbiosis depends on how partners perceive and respond to environmental feedback as continuous signals, reinforcing the role of contextual cue streams in co-adaptive work.

The above streams of studies contribute different but complementary building blocks to the development of our framework. Servicescape research provides the environmental logic by showing that cues embedded in physical, social, and institutional settings shape perception and behaviour. Symbiosis provides the co-adaptation logic by emphasising repeated adjustment between dissimilar actors within a shared habitat. Although symbiosis has previously been applied in marketing to describe mutually beneficial exchange relationships between organisations (Varadarajan and Rajaratnam, 1986), it has not been developed as a construct for theorising the shared human-AI work environment or the environmental cues through which joint work is enacted, coordinated, and retained. Sociotechnical and sociomaterial perspectives provide the configurational logic by showing that collaboration is produced through relations among people, technologies, practices, and organisational arrangements. Sensemaking and adaptation theory then help articulate the process logic by explaining how environmental cues are enacted, selected, and retained as adaptive patterns of joint work. The symbioscape integrates these logics into a layered cue environment for human-machine co-adaptation.

Bringing these streams of literature together motivates a dedicated construct that captures the work environment of human–machine collaboration, rather than treating environment as incidental context. Building on the tiered logic of servicescape research, and guided by symbiosis as a co-adaptation lens, we introduce the *symbioscape* as a way of conceptualising the collaborative work environment of human–machine systems. The term is intended to capture the environmental conditions within which human and AI-enabled actors coexist, interpret cues, and adjust to one another over time.

Based on the above, we propose two important arguments. *First*, the environment of human-machine collaboration is not monolithic but comprises analytically distinct yet related domains of cueing. Some cues are material and informational, shaping what can be perceived and interpreted in the immediate work setting. Others are interactional, shaping how coordination unfolds through rhythms, sequencing, and load. Still others are institutional, shaping what forms of collaboration are authorised, reinforced, and sustained. These domains are clearly related to each other but not interchangeable. Changing a dashboard alters what can be noticed, but not necessarily how turn-taking unfolds. Changing interaction scripts alters coordination, but not necessarily who holds decision rights. Changing governance alters what is permissible and reinforced, but not necessarily what is visible at the workstation.

Second, these environmental domains differ in temporal pace. Organisational change scholarship distinguishes between ongoing, small-cycle adjustments and more episodic, stabilised patterns of change (Weick and Quinn, 1999), while structural inertia helps explain why some arrangements persist even when better alternatives exist (Hannan and Freeman, 1984). Physical-digital cues may shift relatively quickly through interface redesign, layout change, or altered access to information. Socio-relational conditions typically recalibrate at a medium pace as teams adjust interaction patterns, negotiate roles in practice, and settle into new rhythms of coordination. Institutional–ecosystem conditions tend to move slowly because they require formalisation, resourcing, and legitimation through policies, training, and

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organisational structures. This temporal differentiation helps explain why the collaborative environment of human-machine work is better understood as a tiered system.

The symbioscape thus extends the servicescape framework beyond customer–employee encounters to hybrid human–machine work environments by specifying a layered environmental architecture for collaboration. In the next section, this architecture is formalised as a three-tier construct comprising physical–digital, socio-relational, and institutional–ecosystem dimensions, each with distinct cue categories and design-critical cue properties. Table 1 summarises this conceptualisation.

Conceptualising the human-machine symbioscape

Building on servicescape and employee servicescape research that treats environments as formative conditions for perception, coordination, and behaviour (Kotler, 1973; Bitner, 1992; Rosenbaum and Massiah, 2011; De Keyser *et al.*, 2019; Bowen and Schneider, 2014; Kearney *et al.*, 2023), we define the human–machine symbioscape as the collaborative work environment in which humans and AI-enabled machines interact through physical-digital, socio-relational, and institutional-ecosystem cues. This definition treats the work environment as analytically central to collaboration rather than as background context. In line with prior environmental research (Bitner, 1992; Rosenbaum and Massiah, 2011; Kearney *et al.*, 2023), the symbioscape is understood as a structured set of cues that shapes how work is perceived, coordinated, and sustained in practice. In hybrid human–machine settings, these cues matter because they influence what actors can notice, how they relate to one another in ongoing activity, and whether emerging ways of working can be reproduced over time.

The human–machine symbioscape is conceptualised as a three-tier construct. The first tier is physical–digital (PD), the second is socio-relational (SR), and the third is institutional–ecosystem (IE). These tiers are analytically distinct but complementary. The physical–digital tier concerns the perceptual and informational conditions of work. The socio-relational tier concerns the interactional and temporal conditions of coordination. The institutional–ecosystem tier concerns the rules, infrastructures, and legitimating conditions that support and reinforce collaborative work. Together, these tiers specify the principal domains through which the collaborative environment of human–machine work is constituted. The *PD* tier captures hybrid physical and digital environmental cues that constitute the perceptual and informational field for human–machine work. It refers to the aspects of the environment that make system states, action possibilities, and relevant work objects available for perception and interpretation. In this study, the PD tier is expressed through two cue categories; the *first* is shared digital or physical interfaces and artefacts, such as dashboards, status indicators, confidence or uncertainty displays, handover cues, decision aids, and shared screens (PD1). The *second* is spatial layout and access, which includes zoning, proximity, line of sight, placement of machines and displays, visual clutter, background noise, and spatial risk hot spots (PD2). Together, these cue categories shape the degree of transparency and visibility in the collaborative work environment, that is, the extent to which relevant aspects of joint work can be noticed and interpreted at the point of action.

The *SR* tier comprises the temporal and interaction-structuring cues that constitute the coordination field of human–machine work. It refers to the ways in which interaction is patterned, sequenced, and experienced as more or less demanding over time as humans and machines coordinate ongoing activity. For example, in hotels, service robots increasingly complement or replace staff for concierge and recommendation tasks, yet guests' preferences for human versus robotic service depend on whether recommendations concern experiential or material products and the hotel's brand level (Lee and Oh, 2025). For example, in hotels, service robots increasingly complement or replace staff for concierge and recommendation tasks, yet guests still prefer human staff when the request involves uncertainty, experience-based judgements, or a need for more personalised interaction. In this study, the SR tier is expressed through two cue categories; *first*, temporal and workflow sequencing, which

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Table 1. From *Servicescape* to *Symbioscape*

Tier	Servicescape in customer/employee settings based on prior literature	Symbioscape tier definition	Tier categories and illustrative cues	Perceived aggregate cue properties
Physical-digital (PD)	Customer servicescape: Built environment shaping customer perceptions and behaviours through ambient conditions, spatial layout, and artifacts (Bitner, 1992). Illustrative cues: ambience and sensory conditions such as lighting, noise, and crowding; layout and line-of-sight; signs, symbols, and artefacts	Hybrid physical and digital environmental cues that constitute the perceptual and informational field for human-machine work	PD1 Shared digital or physical interfaces and artefacts: dashboards, status indicators, confidence or uncertainty displays, handover cues, decision aids, shared screens	Perceived transparency and visibility of the human-machine work environment, that is, what can be noticed and interpreted about the joint work situation
	Employee servicescape: Workspace conditions including layout, ambient conditions, tools, and workflow design shaping efficiency, safety, and wellbeing (Kearney *et al*., 2023). Illustrative cues: workstation and tool placement; environmental comfort such as noise and lighting; visual access to work objects; physical constraints on movement		PD2 Spatial layout and access: zoning, proximity, line of sight, placement of machines and displays, visual clutter, background noise, spatial risk hot spots	

(*continued*)

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Table 1. Continued

Tier	Servicescape in customer/employee settings based on prior literature	Symbioscape tier definition	Tier categories and illustrative cues	Perceived aggregate cue properties
Socio-relational (SR)	Customer servicescape: The presence and behaviour of others, including employees and other customers, shaping social evaluations, emotions, and behavioural responses (Tombs and McColl-Kennedy, 2003; Harris and Ezeh, 2008). Illustrative cues: social density or crowding, queueing and spacing, civility and misbehaviour, emotional tone, interaction scripts such as greeting and complaint handling, customer mix and similarity, service role behaviours Employee servicescape: Team norms, coordination routines, and interpersonal climate guiding collaboration and communication (Bowen and Schneider, 2014). Illustrative cues: supportive supervision, teamwork norms, cross-role communication routines, shared goals, coordination patterns	Temporal and interaction-structuring cues that constitute the coordination field for human-machine work	SR1 Temporal and workflow sequencing: latency and response time, notification timing, turn-taking protocols, division of initiative, handover checkpoints, parallel versus sequential tasking, escalation scripts, visible workflow maps SR2 Interaction load: alert volume, interruption rate, monitoring burden, repeated feedback demands, exception frequency, override or escalation frequency	Perceived predictability and manageability of the human-machine work environment, that is, whether coordination unfolds in a stable, comprehensible, and manageable way over time
Institutional-ecosystem (IE)	Customer servicescape: Symbolic, natural, and contextual meanings influencing service experience, including orchestration across touchpoints (Rosenbaum and Massiah, 2011; De Keyser *et al.*, 2019). Illustrative cues: normative expectations, legitimacy signals, touchpoint consistency, cultural scripts Employee servicescape: Institutional policies, role structures, training, and governance systems shaping employee performance and alignment (Kearney *et al.*, 2023; Homburg and Stock, 2004). Illustrative cues: standards, protocols, role clarity, accountability, safety, and compliance	Institutional, governance, and ecosystem cues that constitute the rule, legitimacy, and reinforcement field for human-machine work	IE1 Governance and role architecture: accountability and audit trails, decision rights, autonomy boundaries, escalation authority, workflow standards, compliance requirements, risk controls. IE2 Capability infrastructure: onboarding, reskilling, simulation and drills, certification, playbooks, communities of practice, learning loops	Perceived legitimacy and reinforcement of the human-machine work environment, that is, whether human-machine routines are authorised, supported, and stabilised

Source(s): Authors' own work

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includes latency and response time, notification timing, turn-taking protocols, division of initiative, handover checkpoints, parallel versus sequential tasking, escalation scripts, and visible workflow maps (SR1). The *second* is interaction load, which includes alert volume, interruption rate, monitoring burden, exception frequency, and override or escalation frequency (SR2). Together, these cue categories shape the degree of predictability and manageability in the collaborative work environment, that is, whether coordination unfolds in a stable, comprehensible, and manageable way over time.

The *IE tier* captures governance, capability, and reinforcing cues that constitute the rule and legitimacy field of human–machine work. It refers to the organisational and ecosystem-level conditions that authorise, support, and reproduce collaboration between humans and AI-enabled systems. In service ecosystems, customers are resource-integrating actors who co-create value alongside firms, employees, and technologies through shared institutional arrangements (Chandler and Lusch, 2015; Vargo and Lusch, 2016). In this study, the IE tier is expressed through two cue categories; *first* is the governance and role architecture, which includes accountability and audit trails, decision rights, autonomy boundaries, escalation authority, workflow standards, compliance requirements, and risk controls (IE1). The s*econd* is capability infrastructure, which includes onboarding, reskilling, simulation and drills, certification, playbooks, communities of practice, and learning loops (IE2). Together, these cue categories shape the degree of legitimacy and reinforcement, that is, whether human-machine routines are authorised, supported, and stabilised as legitimate ways of working.

The above conceptualisation of human–machine symbioscape extends the servicescape from customer–employee encounters to hybrid human–machine work systems. Its contribution lies not simply in adding technology to existing servicescape categories, but in specifying the environmental cue architecture through which collaborative human–machine work is made perceptible, coordinated, and sustainable. Table 1 summarises this conceptual specification by aligning prior servicescape and employee servicescape insights with the proposed tiers, cue categories, and design-critical cue properties of the human–machine symbioscape.

Symbioscape cues in human-machine collaboration (HMC) research

We position the symbioscape as an integrative advance rather than a conceptual departure. This section shows that prior HMC scholarship already contains environmental cues corresponding to the physical–digital, socio-relational, and institutional–ecosystem tiers developed in Table 1, even though these cues have not been theorised as a layered environmental system. Having defined the human-machine symbioscape as a three-tier environmental architecture, we next show that its constituent cues are already present across the human-machine collaboration literature. Table 2 condenses this evidence by presenting short illustrative extracts from prior studies and coding them against the six cue categories derived in Table 1. The table shows that existing HMC research already points to physical-digital cues that shape perceptibility, socio-relational cues that shape coordination, and institutional-ecosystem cues that shape authorisation and reinforcement. What has been missing is not the presence of these cues in the literature, but their integration into a coherent environmental framework. A fuller verbatim coding record is provided in the Web Appendix.

The importance of environment in HMC research is often acknowledged implicitly. As Van Doorn *et al.* (2023, p. 3) note, "human–technology interactions do not occur in a vacuum." Across the studies reviewed, environmental conditions repeatedly appear in the form of cues that shape what becomes perceptible, how coordination unfolds, and how collaborative arrangements are authorised and sustained. Rather than treating environment as a passive backdrop, these studies portray it as a sociotechnical configuration of people, technologies, and other resources that conditions interpretation, coordination, and adaptive joint work (Kaartemo and Helkkula, 2025; Simón *et al.*, 2024; Danatzis *et al.*, 2025; Azer and Alexander, 2025). Although none of these studies develops a unified environmental construct, together they reveal a recurring cue structure that is consistent with the symbioscape architecture.

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Table 2. Illustrative evidence of symbioscape cues in prior human–machine collaboration research

Study	Type	Setting	Illustrative evidence	PD1	PD2	SR1	SR2	IE1	IE2
Bonetti *et al.* (2023)	E	Hybrid retail	"Materialities are tangible facets like objects or technologies used within practices" (p. 871); "contextual knowledge (i.e. know-who, know-where, know-when)" supports practice co-evolution (p. 882)	Y	Y	Y	–	I	Y
Kaartemo and Helkkula (2025)	C	Service ecosystem	"A service ecosystem is a configuration of people, technologies and other resources interacting to create mutual value" (p. 292); value cocreation depends on "institutional arrangements of service ecosystems" (p. 301)	–	–	–	–	Y	–
Van Doorn *et al.* (2023)	C	Organisational frontlines	"We consider that AT can be . . . worker-facing, such as AT-enabled knowledge-based systems supporting a worker's decision-making" (p. 2); AT integration is "contingent on task division, leadership, and work design" (p. 10)	Y	–	–	–	Y	–
Tan *et al.* (2025)	E/C	Hybrid hospitality	"HRC is defined as a synergistic partnership in which humans and robots jointly perform tasks" (p. 2); robots "engage in interpersonal communications with employees" (p. 6)	–	–	Y	Y	–	–
Fiestas Lopez Guido *et al.* (2025)	E/C	Hybrid retail	Humanoid service robots are expected to "work seamlessly alongside human employees" (p. 603); "Master-servant relationships imply a social order" with unequal rights and responsibilities (p. 605)	–	–	Y	–	Y	–

(*continued*)

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Table 2. Continued

Study	Type	Setting	Illustrative evidence	PD1	PD2	SR1	SR2	IE1	IE2
Danatzis *et al.* (2025)	C	Organisational frontlines	Human-technology collaboration shifts work toward "the delegation and coordination of interdependent tasks at the service process level" (p. 3); "Both partners need to provide and adjust to mutual feedback as they work towards a shared goal . . ." (p. 4); "decision-making authority for task execution and coordination is shared between employees and technology" (p. 4); ". . . foster metaknowledge for each of these fit appraisals." (p. 10)	–	–	Y	Y	Y	Y
Kunz *et al.* (2025)	C	Human-machine service work	"Effective human-machine collaboration requires intuitive user interfaces" (p. 480); engagement patterns are characterised by "coordination cues," "supervisory cues," and "team goal cues" (p. 482)	Y	–	Y	–	Y	–
Simón *et al.* (2024)	C	Organisational human-AI teaming	"Integrating AI as a unique, new team member" (p. 2); "Productive dialogue assumes agents . . . engage in mutual interaction" (p. 2)	–	–	Y	–	Y	–

(*continued*)

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Table 2. Continued

Study	Type	Setting	Illustrative evidence	PD1	PD2	SR1	SR2	IE1	IE2
Shanks *et al.* (2025)	E/C	Hybrid healthcare	Cobotic service teams include "a human and a robot, collaborating in a co-located space, to serve a customer" (p. 464); "roles shared by employees and robots (robots in superordinate roles as team leaders and humans in subordinate roles as assistants, or vice versa" (p. 464); "organizations need to offer trainings" to support adaptation to evolving robotic capabilities (p. 481)	–	Y	–	–	I	Y
Azer and Alexander (2025)	C	Human-machine engagement	"Human-machine engagement is likely to differ significantly from human-human engagement due to structural asymmetries" (p. 113); "AI's perceived complexity can hinder adoption" (p. 120)	–	–	–	–	Y	–
Le *et al.* (2025)	E/C	Digital service	"HE-DE frontline co-presence . . . visible sequencing of HE and DE in a customer-facing process" (p. 189); "Coordination cue . . . visible communication regarding the orchestration of work handover" (pp. 189–190)	Y	–	Y	–	I	–

Note(s): C = conceptual; E = empirical; E/C = empirical paper with conceptual relevance. PD1 = shared digital or physical interfaces and artefacts; PD2 = spatial layout and access; SR1 = temporal and workflow sequencing; SR2 = interaction load; IE1 = governance and role architecture; IE2 = capability infrastructure. Y = explicit evidence; I = implicit or partial evidence; – = no clear evidence

Physical–digital tier of the symbioscape

The physical–digital tier is evident in prior HMC research wherever the environment makes human–machine activity perceptible and interpretable. Across the studies in Table 2, this occurs through two recurring cue categories. The first concerns shared interfaces and artefacts, that is, the visual, digital, and material devices through which system states, recommendations, handovers, and task cues are rendered visible. The second concerns spatial layout and access, that is, the arrangement of bodies, machines, and work objects in ways that shape proximity, line of sight, movement, and perceptual access.

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The strongest evidence for PD1 appears in studies that emphasise interfaces, coordination cues, decision-support tools, and other visible artefacts of human–machine work. Van Doorn *et al.* (2023), Kunz *et al.* (2025), and Le *et al.* (2025) all point to worker-facing systems, intuitive user interfaces, and visible handover cues as mechanisms through which machine activity becomes legible in practice. Bonetti *et al.* (2023) similarly show that interfaces and other material artefacts require employees to learn how to recognise, follow, and make sense of the information they present, rather than simply receiving it passively. Across these studies, interfaces and artefacts do not merely transmit information. They shape whether machine states, task boundaries, and transition points can be noticed and interpreted in the course of work.

The evidence for PD2 appears in studies that discuss co-location, working alongside robots, and the spatial conditions of collaboration. Bonetti *et al.* (2023) underline "know-where" and the environment in which practice change is enacted, pointing to the significance of spatial access and material arrangement. Shanks *et al.* (2025) explicitly describe cobotic teams as humans and robots collaborating in a co-located space to serve a customer. Under the current Table 1 logic, such findings are best interpreted as part of spatial layout and access, because the perceptibility of others depends on how the environment arranges bodies, machines, movements, and lines of access.

Taken together, these studies demonstrate that physical–digital environment matters when it makes joint work perceptible. Shared interfaces and artefacts render system states and handovers intelligible, while spatial layout and access determine whether human and machine activity can be visually and materially monitored in context. In this sense, the literature supports the view that the physical–digital tier gives rise to perceived transparency and visibility in human–machine work environments. This pattern is especially salient in service settings, where employees often need to interpret machine outputs and intervene in real time while maintaining service continuity.

Socio-relational tier of the symbioscape

The socio-relational tier is evident in prior HMC research wherever collaboration is shaped by recurring interaction structures rather than by mere co-presence. Across the studies in Table 2, two patterns recur most clearly. The first concerns temporal and workflow sequencing, that is, how interaction is ordered through turn-taking, handovers, response timing, division of initiative, and escalation sequences. The second concerns interaction load, that is, the volume, intensity, and burden of ongoing exchanges between humans and machine partners, including repeated feedback demands, monitoring requirements, interruption, and escalation pressure. For instance, in a hotel front-desk setting, robots can handle easy, repetitive guest requests, while staff focus on more complex, experience-based, or emotionally sensitive interactions (Lee and Oh, 2025). The evidence for SR1 appears in studies that describe collaboration as structured through patterned sequences of action. Kunz *et al.* (2025) identify coordination, supervisory, and team-goal cues that make the order and structure of collaboration explicit. Le *et al.* (2025) similarly show that visible sequencing between human and digital employees shapes how collaboration is understood in service settings. Danatzis *et al.* (2025) emphasise the delegation and coordination of interdependent tasks and the regular hand-offs of subtasks, while Bonetti *et al.* (2023) show that AI-enabled practice change unfolds through recognisable timing structures. Across these studies, what matters is not simply that interaction occurs, but that it occurs in patterned, recognisable, and actionable sequences.

The evidence for SR2 appears in studies that highlight the volume, frequency, intensity, or burden of interaction. In this respect, Danatzis *et al.* (2025) point to mutual feedback demands between human and technological partners, while Tan *et al.* (2025) highlight ongoing interpersonal communication between employees and robots. Complementing this, prior empirical work in the broader HMC literature, including the studies summarised in Table 2, shows that monitoring burdens, interruptions, and repeated coordination demands can create

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stress and pacing pressure in hybrid work. The key point is that socio-relational environments differ not only in how interaction is sequenced, but also in how demanding it becomes to sustain.

Taken together, the socio-relational literature shows that human–machine collaboration depends not only on whether partners interact, but on how that interaction is temporally structured and how burdensome it becomes. Temporal and workflow sequencing create order and mutual understanding, while interaction load influences whether coordination remains manageable or becomes disruptive. The studies therefore support the view that the socio-relational tier gives rise to perceived predictability and manageability in the collaborative work environment. This is especially important in service contexts, where frontline work is often time-pressured, interruption-prone, and dependent on smooth coordination across multiple actors.

Institutional-ecosystem tier of the symbioscape

The institutional–ecosystem tier is evident in prior HMC research wherever collaboration is shaped by formal or semi-formal structures that authorise, reinforce, and reproduce human–machine work over time. Across the studies in Table 2, these cues cluster around two categories. The first concerns governance and role architecture, including task division, accountability, authority, autonomy boundaries, and organisational design. The second concerns capability infrastructure, including training, readiness, skill development, and other forms of institutional support that allow collaborative routines to develop and persist.

The evidence for IE1 is particularly strong. Van Doorn *et al.* (2023) explicitly link the consequences of autonomous technologies to leadership and work design. Simón *et al.* (2024) show that AI must be integrated into existing socio-technical systems and authority arrangements if it is to function as a teammate. Kunz *et al.* (2025) point to adaptable workflows and standardised service processes as structural resources for implementation, while Kaartemo and Helkkula (2025) frame rules, social norms, and institutional arrangements as central to human-AI value cocreation. In service ecosystems, customers are not external to the collaborative environment but resource-integrating actors who co-create value alongside firms, employees, and technologies through shared institutional arrangements (Chandler and Lusch, 2015; Vargo and Lusch, 2016). Danatzis *et al.* (2025) add that decision-making authority and delegation mechanisms must be established explicitly, and both Fiestas Lopez Guido *et al.* (2025) and Shanks *et al.* (2025) show that role allocation and hierarchy are consequential in hybrid human-robot service teams. Across these studies, governance and role architecture shape what kinds of collaboration are authorised, how agency is distributed, and who remains accountable when intelligent systems are involved.

The evidence for IE2 is present wherever studies emphasise training, readiness, metaknowledge, and organised capability development. Danatzis *et al.* (2025) explicitly identify complementary readiness and metaknowledge as enabling conditions for successful human-technology synergy. Bonetti *et al.* (2023) imply a learning infrastructure through contextual knowledge and practice co-evolution. Most directly, Shanks *et al.* (2025) argue that organisations need to offer training that helps employees adapt to evolving robotic capabilities and strengthen their own human skills. These cues indicate that collaboration is not sustained by governance alone; it also depends on infrastructures that help employees learn how to interpret, manage, and reproduce new routines of human–machine work.

Taken together, the institutional–ecosystem literature shows that hybrid collaboration becomes durable only when it is supported by explicit structures of authorisation and capability development. Governance and role architecture specify what is legitimate and accountable, while capability infrastructure enables emerging routines to be learnt, reinforced, and retained. The studies therefore support the view that the institutional–ecosystem tier gives rise to perceived legitimacy and reinforcement in the collaborative work environment.

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Overall, Table 2 shows that prior HMC research already contains the raw environmental elements of the symbioscape, but in a fragmented and largely implicit form. The literature repeatedly points to perceptual and informational cues, interaction-structuring cues, and legitimating and reinforcing cues, yet it has not brought these together into a single layered construct. The contribution of the symbioscape is therefore not to introduce an entirely new set of factors, but to organise dispersed environmental insights into a coherent architecture that can be theorised and linked to distinct mechanisms of human–machine adaptation.

Symbioscape, sensemaking, and adaptation

To explain how the human-machine symbioscape matters for collaborative work, we draw on Weick's sensemaking perspective. Sensemaking is an effective lens because it treats environments not as passive backdrops, but as streams of cues that actors notice, interpret, and stabilise into workable patterns of action (Weick, 1979, 1995), and this logic fits the symbioscape closely. The symbioscape specifies the environmental cue architecture of human-machine collaboration, while sensemaking explains how those cues are translated into adaptive responses. In Weick's terms (1979, 1995), enactment refers to the way actors notice and categorise cues from, and make sense of, their environment. Selection refers to the interpretive and coordinative process through which plausible responses are chosen and mutual expectations are formed. Finally, retention refers to the preservation and reinforcement of those responses so that they become available for future action. The symbioscape structures these environmental conditions under which enactment, selection, and retention become easier or harder to accomplish, leading to different adaptation outcomes.

Our conceptual framework, shown in Figure 1, specifies symbioscape as an adaptive infrastructure, in which the three tiers of the symbioscape activate distinct sensemaking processes and thereby support different forms of adaptive response. The tiers identify where and how environmental changes occur, while sensemaking explains how these changes are translated into interpretable aggregate cues or signals that shape the speed, effectiveness, and persistence of adaptation in collaborative work. In the next sections, we introduce and follow the logic of our proposed conceptual framework.

Across disciplines, adaptation has been described as cognitive adjustment, organisational learning, structural realignment, and resilience under changing conditions (Argyris and Schön, 1978; Lawrence and Lorsch, 1967; Folke *et al.*, 2010). For the present study, however, the most

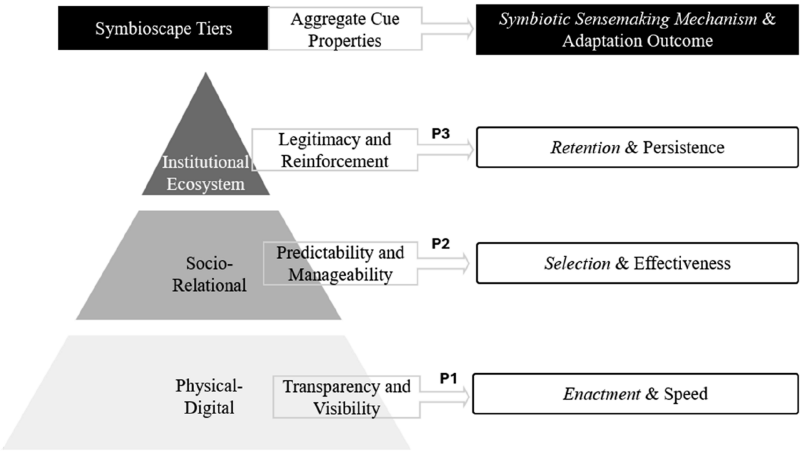


Figure 1. Conceptual framework. Source: Authors' own work

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relevant aspect is team adaptation, because human-machine collaboration unfolds through joint adjustment between interdependent actors rather than through isolated individual responses. Team adaptation research defines adaptation as the modification of actions, coordination patterns, or structures in response to changing demands and salient cues, which are central inputs into adaptive performance (Burke *et al.*, 2006; Baard *et al.*, 2014). Building on this literature, we conceptualise adaptation in human-machine collaboration as a process of cue-based adjustment through which human and AI-enabled actors recalibrate how they work together under changing environmental conditions.

Drawing on team adaptation research and complementary work on retention and institutionalisation, we distinguish three adaptation process outcomes: adaptation speed, adaptation effectiveness, and adaptation persistence (Marks *et al.*, 2000; Burke *et al.*, 2006; Baard *et al.*, 2014; Weick, 1995; Scott, 2001; Nelson *et al.*, 2007). *Adaptation speed* refers to how quickly human-machine actors recalibrate and adjust their actions when encountering salient cues (Marks *et al.*, 2000; Burke *et al.*, 2006). *Adaptation effectiveness* refers to the quality and fit of those adjustments, that is, whether coordination becomes more accurate and better fitted to the task (Baard *et al.*, 2014; Burke *et al.*, 2006). *Adaptation persistence* concerns the durability of these adjustments and modifications over time as they become reproduced, reinforced, and retained in routines, roles or organisational arrangements (Nelson *et al.*, 2007; Scott, 2001). Importantly, adaptation outcomes capture different aspects of adaptive performance, and specify how human-machine collaboration changes under different environmental conditions.

The physical-digital tier is most closely associated with enactment because it shapes what can be noticed and interpreted in the immediate work environment. As specified in Table 1, this tier is expressed through shared digital or physical interfaces and artefacts (PD1), and spatial layout and access (PD2). Together, these cues determine whether task states, handovers, responsibilities, and anomalies are perceptible at the point of action. Evidence from prior research suggests that when interfaces are legible and spatial access is well designed, actors can more easily perceive ongoing work states, anticipate next steps, and reduce uncertainty in real time (Endsley, 1995; Hutchins, 1995; Koo *et al.*, 2015). According to Weick (1979, 1995), these conditions shorten enactment cycles by making it easier to categorise and interpret relevant cues from the environment. The primary adaptive outcome is therefore speed. Physical-digital cues do not guarantee good coordination on their own, but they affect how rapidly human and machine actors can begin to adjust once conditions change. This is especially important in service settings, where frontline employees often must interpret machine outputs and intervene immediately while maintaining service continuity. For example, in a retail store, handheld devices that show stock availability and product location, together with clearly organised aisles, allow employees to identify where intervention is needed and adjust tasks quickly. Thus, we propose that:

P1. When physical-digital cues increase the transparency and visibility of joint work, they accelerate adaptation by shortening enactment cycles in human-machine collaboration.

The socio-relational tier is most closely associated with selection because it shapes how interaction becomes patterned, workable and manageable over time. As indicated in Table 1, this tier is expressed through temporal and workflow sequencing (SR1), and interaction load (SR2). Prior research suggests that clearly structured interaction patterns, combined with manageable interaction load, are associated with higher-quality coordination outcomes. Structured sequencing and defined escalation routines are linked to smoother coordination and reduced error in hybrid human-robot teams (Andronas *et al.*, 2021), whereas environments characterised by excessive alerts, unpredictable interruptions, high monitoring burden, or repeated feedback demands are associated with stress, pacing pressure, and cognitive strain (Phillips *et al.*, 2025; Pasparakis *et al.*, 2023). From a sensemaking perspective, these dynamics stabilise selection because selection depends not only on noticing cues, but on actors

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being able to align interpretations and settle on plausible coordinated responses. Meaning is validated through recurrent interactions (Weick, 1995), and in human-machine settings, predictable turn-taking, consistent escalation pathways, and manageable feedback demands allow actors to learn how their counterparts respond and to coordinate appropriate action. By contrast, when interaction is poorly sequenced or excessively demanding, actors may still notice what is happening, but struggle to choose and sustain an effective response. The primary adaptive outcome is therefore effectiveness. Socio-relational cues shape whether adjustment becomes accurate, coordinated, and functionally aligned across actors. Therefore, we propose that:

P2. When socio-relational cues increase predictability and manageability of interaction, they enhance adaptation effectiveness by stabilising selection processes in human-machine collaboration.

The institutional-ecosystem tier is most closely associated with retention because it shapes whether new patterns of collaboration are reinforced and reproduced over time. As specified in Table 1, this tier is expressed through governance and role architecture (IE1), and capability infrastructure (IE2). Prior research suggests that explicit governance arrangements and structured capability development are consistently associated with sustained practice evolution, role clarity, and workflow alignment (Bonetti *et al.*, 2023; Danatzis *et al.*, 2025; Tuomi *et al.*, 2025; Castaneda *et al.*, 2025). In hybrid service and healthcare contexts, governance mechanisms and formal training help stabilise cobotic coordination over time (Shanks *et al.*, 2025; Tuomi *et al.*, 2025). Following Weick (1995), retention occurs when enacted and selected responses are reproduced as legitimate and repeatable ways of working. Governance structures codify expectations, while capability infrastructure embeds them through repeated training, simulation, and review. The primary adaptive consequence is therefore persistence. Institutional-ecosystem cues determine whether collaborative adjustments become durable features of the work system rather than temporary improvisations. Thus, we put forward the following proposition:

P3. When institutional-ecosystem cues provide stable expectations and reinforce legitimate new patterns of interaction, they enable adaptation persistence by strengthening retention processes in human-machine collaboration.

Although each proposition associates a tier with a primary sensemaking process and adaptation outcome, the tiers are likely to interact. Physical–digital visibility may accelerate enactment when socio-relational routines are clearly specified. Similarly, socio-relational coordination may improve adaptation effectiveness only when institutional arrangements authorise employees to override, escalate, or reinterpret machine outputs. Conversely, institutional governance can also constrain adaptation if rules limit experimentation with new interface cues or workflow practices. Furthermore, these dynamics are likely to vary across service contexts, making some cue families more salient than others. For instance, in personalised and emotionally laden hospitality settings, socio-relational cues and sequencing may be particularly salient; in healthcare, where risk and accountability are especially salient, institutional–ecosystem cues are likely to be dominant, whereas in retail, physical–digital visibility and spatial access may be especially important for rapid adjustment. Future research should therefore examine not only the independent effects of each tier, but also their cross-tier interactions and their conditional effects across different service conditions and contexts.

Taken together, these arguments suggest that the symbioscape is not merely a context for adaptation, but the three tiers constitute an integrated architecture of adaptive capacity in human-machine systems. Physical-digital cues primarily support the enactment of relevant conditions and therefore influence adaptation speed. Socio-relational cues primarily support the selection of coordinated responses and therefore influence adaptation effectiveness. Institutional-ecosystem cues primarily support the retention of legitimate and repeatable practices and therefore influence adaptation persistence. The three tiers are analytically

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distinct but complementary, and their joint configuration determines whether human-machine collaboration improves, stabilises, or deteriorates over time. The symbioscape-sensemaking-adaptation framework therefore conceptualises the work environment as a layered infrastructure through which collaborative work is noticed, coordinated, and retained.

Research and managerial implications

This article advances human–machine collaboration research by introducing the symbioscape as a structured environmental architecture that shapes how collaboration is enacted, coordinated, and retained over time. Whereas much of the human–AI collaboration literature has focused on task allocation, capability complementarities, or performance outcomes, the symbioscape framework shifts attention to the layered environmental cues that shape how actors notice, interpret, coordinate, and legitimise joint work. Existing models often treat the work environment as background context or implementation setting. By contrast, this framework conceptualises it as an active and designable system composed of physical–digital, socio-relational, and institutional-ecosystem tiers. By linking these tiers to enactment, selection, and retention, and to adaptation speed, effectiveness, and persistence, the framework clarifies how environmental design can explain variation in adaptive performance across otherwise similar human–machine arrangements. For research, this framework opens three main directions. First, it highlights the need to operationalise the environmental cues embedded in each tier of the symbioscape. Future studies could develop and validate measurement instruments for constructs such as shared interfaces and artefacts, spatial layout and access, temporal and workflow sequencing, interaction load, governance and role architecture, and capability infrastructure. Although some of these elements already have partial precedents in adjacent literature, the present framework calls for a more systematic and tier-specific operationalisation of the human-machine work environment. *Second*, the framework invites empirical examination of how distinct cue categories contribute to different adaptation outcomes. Future research can examine whether physical–digital cues primarily influence adaptation speed, socio-relational cues primarily influence adaptation effectiveness, and institutional-ecosystem cues primarily influence adaptation persistence. *Third*, future work should examine cross-tier dynamics. For example, physical-digital transparency may accelerate enactment only when socio-relational coordination is sufficiently predictable and manageable, while institutional support may determine whether short-term improvements in coordination become durable organisational routines. Such work would clarify how the tiers reinforce or constrain one another rather than operating independently.

These research opportunities are particularly important in service settings. Hospitality, retail, healthcare, and call-centre environments are characterised by customer presence, temporal pressure, emotional demands, and operational variability. In such contexts, the quality of human-machine collaboration depends not only on technological capability, but also on whether the work environment makes machine activity intelligible, coordination manageable, and new routines sustainable. The symbioscape therefore offers a way to connect broader human-machine collaboration theory more directly to service research on frontline work, service design, and technology-infused service delivery.

For managers, the symbioscape framework provides a structured architecture for designing AI-enabled workplaces rather than merely implementing AI systems. While much managerial discourse still centres on technology adoption, automation efficiency, or return on investment, the symbioscape draws attention to the conditions under which collaboration with AI actually becomes viable in practice. Managers are encouraged to treat visibility, workflow structuring, interaction load, governance, and capability supports as design variables rather than assuming that the technical quality of the system alone will produce effective collaborative performance.

To make our proposed framework actionable, Table 3 provides a diagnostic toolkit for practice. It helps managers identify where adaptation is likely to stall by focussing attention on three simple questions: can people see what the machine is doing, can people and machines

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Table 3. Diagnostic toolkit for designing adaptive human-machine work environments

Symbioscape tier	Diagnostic question	What managers should look for	Design levers	Likely adaptation problem if absent
Physical-digital	Can people see and interpret what the machine is doing?	Legible system states, clear handovers, visible confidence signals, workable layout and access	Improve dashboards, prompts, handover cues, placement, line of sight	Slow adaptation
Socio-relational	Can people and machines coordinate in a predictable and manageable way?	Clear turn-taking, manageable alerts, predictable escalation, visible workflow sequencing	Redesign interaction protocols, batching, escalation scripts, workflow maps, workload-shaping rules	Ineffective adaptation
Institutional-ecosystem	Is the collaboration authorised, supported and reinforced over time?	Clear accountability, explicit decision rights, autonomy boundaries, training, playbooks, review loops	Strengthen governance, role architecture, onboarding, reskilling, learning routines	Fragile adaptation

coordinate in a stable and manageable rhythm, and is the collaboration formally supported and reinforced? These questions direct attention to the specific environmental conditions that make adaptive human-machine work possible.

At the physical-digital level, managers should ask whether employees can see what the AI or robot is doing, what happens next, and when intervention is required. Clear status indicators, shared dashboards, explicit handover cues, and well-designed spatial access conditions can make the joint work situation more interpretable and thereby accelerate activity-level adjustment. At the socio-relational level, managers should examine whether turn-taking, escalation, and feedback occur in a stable and manageable rhythm. Interaction protocols, notification rules, batching, escalation thresholds, and workload-shaping mechanisms can improve the predictability and manageability of coordination and thereby strengthen adaptation effectiveness. This is particularly important in hospitality and other frontline service contexts, where employees must manage guest-facing uncertainty, emotional labour, and service recovery while coordinating with intelligent systems in real time. At the institutional-ecosystem level, managers should ask whether accountability, decision rights, autonomy boundaries, and training infrastructures are explicit and reinforced. Governance structures, role architectures, onboarding, reskilling, and learning loops can convert local adjustments into legitimate and durable ways of working, thereby strengthening adaptation persistence.

The following service examples illustrate how these design principles can be applied in practice. A retail replenishment system supported by aisle-level prompts and exception dashboards shows how physical-digital visibility can support faster adjustment. A call-centre workflow with explicit escalation triggers and batched alerts shows how socio-relational structuring can improve coordination quality while reducing overload. A hospital cobot deployment with formal override protocols, simulation-based training, and post-incident review processes shows how institutional support can stabilise collaboration over time. These examples help translate the framework from an abstract conceptual architecture into a practical design lens for diagnosing and improving AI-enabled workplaces.

Finally, the framework also has broader societal implications. Symbioscape design shapes not only performance but also the distribution of work, responsibility, and skill in AI-enabled service systems. It provides future scholars with a diagnostic lens for examining how human-

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AI workplace design changes the skills employees need to work effectively with intelligent agents. Well-designed symbioscapes can make machine activity visible, preserve human input and discretion, and keep interaction demands manageable. In contrast, poorly designed symbioscapes with ambiguous role architectures may blur human-AI boundaries and accountability, intensify monitoring burdens, increase cognitive overload by shifting more work onto frontline employees, or create dependency on opaque systems. These issues are especially important in service contexts, where customers, employees, and intelligent systems jointly shape service outcomes in real time.

Overall, the symbioscape lens positions environmental design as a strategic lever for shaping adaptive capacity in human-AI collaboration. By systematically structuring physical–digital visibility, socio-relational predictability and manageability, and institutional legitimacy and reinforcement, managers can shape not only whether humans and AI work together, but how quickly they adjust, how effectively they coordinate, and how durably those new patterns of collaboration are retained.

Supplementary material

The supplementary material for this article can be found online.

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