Blancher, M., Florez-Perez, L. & Murguia, D. (2025). The Adaptive Interoperability Journey: Navigating Fragmentation in Digital AEC Projects for IGLC33 papers. In O. Seppänen, L. Koskela, & K. Murata (Eds.), *Proceedings of the 33rd Annual Conference of the International Group for Lean Construction* (IGLC33) (pp. 1428–1439). https://doi.org/10.24928/2025/0171

THE ADAPTIVE INTEROPERABILITY JOURNEY: NAVIGATING FRAGMENTATION IN DIGITAL AEC PROJECTS

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ABSTRACT

The architecture, engineering, and construction sector's digital transformation has been hindered by persistent interoperability challenges. These issues have undermined productivity despite the advent of advanced technologies such as building information modelling and computational design. This study investigates how design team managers in the United Kingdom address interoperability issues by focusing on both technical and organisational factors. Using a qualitative approach based on interviews, the research explores how managers experience these challenges in practice and how technical solutions and organisational strategies co-evolve. From this investigation, the adaptive interoperability journey (AIJ) model was developed to guide design teams in enhancing interoperability by implementing organisational learning through three phases: alignment, mastery-building, and regenerative innovation. The AIJ model offers strategic principles to assist organisations in effectively adapting to their specific circumstances and navigating digital transformation challenges. This work contributes to the lean construction literature by aligning theory with practice to improve collaboration and productivity in fragmented project environments.

KEYWORDS

digital transformation, interoperability, BIM, ISO 19650, learning organisation.

INTRODUCTION

The architecture, engineering, and construction (AEC) sector faces a pressing need for digital transformation to address longstanding productivity challenges. Despite advanced technologies such as building information modelling (BIM), computational design, and design automation, productivity growth remains critically low (Osorio-Gómez et al., 2024; Winfield, 2020). One significant impediment is interoperability—defined as the seamless sharing of data across software applications and disciplines—a foundational requirement for Construction 4.0 (Forcael et al., 2023; Sawhney et al., 2020). The design stage, characterised by intensive multidisciplinary collaboration and the use of diverse digital tools, is particularly prone to interoperability challenges (Galaz-Delgado et al., 2021; Herrera et al., 2020; Stowe et al., 2020). Advanced technologies promise improved efficiency, cost savings, and customer satisfaction (Sawhney et al., 2020; Wang et al., 2022). However, their integration is hampered by the

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fragmented, project-based nature of the AEC sector (Osorio-Gómez et al., 2024). This fragmentation exacerbates interoperability issues, leading to inefficiencies, project delays, and escalating costs (Akinradewo et al., 2023; Osorio-Gómez et al., 2024).

Interoperability challenges extend beyond technology. Organisational interoperability—aligning processes and fostering collaboration across disciplines—remains a critical yet underexplored factor (Osorio-Gómez et al., 2024; Sattler et al., 2021). In a volatile, uncertain, complex, and ambiguous (VUCA) environment, high expectations for digital transformation are often misaligned with persistent integration challenges (Agafonova et al., 2023; Karmakar & Delhi, 2021; Stefanescu, 2020). Addressing interoperability requires strategies which balance technical and organisational dimensions whilst accounting for the AEC sector's inherent complexities (Osorio-Gómez et al., 2024; Winfield, 2020).

This study examines how design team managers in the United Kingdom navigate interoperability challenges. The research adopts a constructivist grounded theory methodology using semi-structured interviews with design team managers from UK-based AEC firms and builds on insights from a previous study (Blancher, 2023). It also introduces the adaptive interoperability journey (AIJ) model, which emerged from the data analysis as a grounded theory and addresses interoperability challenges by fostering alignment, mastery, and innovation across design teams.

BACKGROUND

ORGANISATIONAL INTEROPERABILITY AND ISO 19650

Interoperability remains a critical challenge in the AEC sector, particularly as digital transformation reshapes traditional workflows (Winfield, 2020). Many frameworks address different dimensions of interoperability. Notably, the International Organization for Standardization (ISO) 19650 is a widely recognised standard series for managing information exchange and supporting collaboration in digital construction projects (ISO, 2018). This section examines how ISO 19650 aligns with broader organisational interoperability needs, assessing its strengths and limitations in addressing the dynamic issues faced by design teams.

The ISO 19650 series establishes a comprehensive framework for managing information across the lifecycle of built assets, focusing on standardised workflows and responsibilities (Godager et al., 2022). Rooted in BIM principles, the standard aims to simplify data exchange and enhance stakeholder collaboration by defining a common data environment, assigning clear information management roles, and setting protocols for delivering and exchanging project information (Godager et al., 2022). Whilst primarily technical, ISO 19650 also impacts organisational processes by promoting consistent data practises across disciplines. It provides a structured pathway to achieve clarity and consistency in workflows, reducing inefficiencies caused by miscommunication or fragmented practises (Winfield, 2020). Thus, it helps align technical and organisational practises in AEC projects.

Implementing ISO 19650 often requires significant organisational changes, such as adjustments in workflows, staff training, and shared procedures (Godager et al., 2022). These adaptations highlight the intersection of technical and organisational interoperability: effective implementation hinges on aligning processes, roles, and even team culture across multidisciplinary groups (Osorio-Gómez et al., 2024).

One notable organisational implication of ISO 19650 is its reliance on standardisation to foster collaboration (Bolpagni et al., 2022). Whilst this provides consistency, it can also constrain the flexibility required in dynamic, project-based environments. For example, design teams may struggle to strictly adhere to predefined standards without compromising their ability to innovate or adapt to emerging issues and client requirements (Galaz-Delgado et al., 2021). ISO 19650 thus addresses foundational interoperability needs but does not fully account for the iterative and adaptive processes crucial for navigating fragmented environments. The standard's emphasis on compliance and standardisation, although beneficial, may overlook the importance of fostering creativity, decentralised decision-making, and organisational learning (Godager et al., 2022; Hall & Hasan, 2023). These gaps underscore the need for complementary approaches which integrate ISO 19650's principles with broader organisational frameworks.

Learning, Adaptation, and Knowledge Integration

Organisational learning and knowledge integration frameworks offer strategies for building adaptability and collaboration in dynamic environments. Concepts such as Senge's (2006) learning organisation and the socialisation, externalisation, combination, internalisation (SECI) model (Nonaka & Takeuchi, 1995) provide insights into how teams can develop the adaptability and knowledge-sharing mechanisms required to thrive in VUCA environments. These frameworks emphasise the iterative nature of learning and can help embed organisational capabilities alongside technical standards.

Senge's (2006) learning organisation theory, through its five disciplines—systems thinking, shared vision, team learning, mental models, and personal mastery—promotes a holistic approach to problem-solving. By aligning teams around common goals and encouraging collaboration and innovation, these principles can help bridge the gap between technical and organisational dimensions (Flood, 2002; Senge, 2006). Kolb's experiential learning theory (2014) complements these ideas by framing learning as an iterative four-stage cycle: concrete experience, reflective observation, abstract conceptualisation, and active experimentation (Kolb & Kolb, 2005). This provides a structured approach to continual adaptation and problem-solving. Together, these frameworks emphasise adaptability, collaboration, and continuous learning, helping organisations refine workflows and develop innovative solutions (Leavitt, 2011; Senge, 2006).

Knowledge-creation models, such as SECI, provide perspectives on how organisations can adopt new technologies and create organisational knowledge. The SECI model outlines how knowledge is created and shared through socialisation, externalisation, combination, and internalisation, embedding best practises into daily operations. Similarly, Rogers's diffusion of innovation theory (2003) describes the stages of adoption—knowledge acquisition, persuasion, decision-making, implementation, and confirmation—and can explain how organisations integrate digital tools into workflows. In addition, Michaud et al.'s (2019) phased approach to standardisation—thinking, operationalisation, and diffusion—offers actionable insights into integrating structured processes with iterative learning models in the AEC sector.

Although these frameworks are relevant to digital transformation, they also have limitations. Senge (2006) and Kolb (2014) focus on cultural and iterative processes but overlook issues of scalability and technical complexity, making them less applicable to diverse, multi-stakeholder environments. Similarly, Rogers (2003) and the SECI model emphasise internal knowledge flows, neglecting the critical role of external collaboration and adaptive learning required in dynamic sectors such as AEC.

Addressing these gaps requires integrating the iterative learning processes of Senge (2006) and Kolb (2014) with the knowledge-sharing mechanisms of Rogers (2003) and the SECI model whilst also adopting standardisation strategies like those proposed by Michaud et al. (2019). By tailoring these approaches to fragmented multi-stakeholder contexts, organisations can better navigate the technical, semantic, and organisational dimensions of interoperability. This integration enables sustainable digital transformation and enhanced collaboration.

Research Objectives

Despite extensive research on technical interoperability, there remains limited understanding of how organisational factors—such as managerial practises, organisational learning, and team autonomy—impact interoperability within fragmented AEC project environments. This study addresses this gap by exploring how design teams in the AEC sector navigate interoperability challenges, with the following research objectives:

- RO1: Understand how design teams experience interoperability challenges in practise.
- RO2: Examine the strategies teams employ to maintain productivity amidst these challenges.
- RO3: Explore how organisational dynamics influence the teams' ability to address interoperability issues.

By targeting these gaps, the study can enhance the understanding of current practises and offer theoretical insights into organisational dimensions, guiding design teams in navigating digital transformation challenges.

RESEARCH METHODOLOGY

This study adopted a constructivist grounded theory approach (Charmaz, 2014) to investigate interoperability challenges in the AEC sector. Constructivist grounded theory is well-suited to examining complex, context-dependent phenomena as it generates theory from the data, ensuring alignment with the participants' real-world experiences. This methodology enables an in-depth exploration of the organisational and interpersonal dynamics influencing digital transformation and the development of the AIJ model. This methodology is philosophically grounded in the belief that knowledge emerges through interactions between participants and researchers; consequently, clearly distinguishing findings from interpretation is inherently problematic, if not impossible (Charmaz, 2014).

PARTICIPANTS

A purposive sampling strategy was used to recruit individuals with direct experience managing or leading design teams. The participants typically held roles such as digital transformation specialist, interface coordinator, BIM manager, associate director, or principal engineer. These professionals offered informed perspectives on organisational productivity challenges and team capabilities. The sample comprised 14 senior participants from diverse disciplines including rail, civil engineering, architecture, and construction management, providing a nuanced understanding of interoperability challenges across various contexts. Interviews were conducted until reaching data saturation, as no new themes emerged by about the twelfth interview (Corbin & Strauss, 2015). Thus, a total of 14 interviews was deemed sufficient to capture a comprehensive range of insights.

The participants were primarily based in the United Kingdom, taking advantage of the region's advanced adoption of digital technologies in the AEC sector. Each had at least 10 years' professional experience, ensuring their viewpoints reflected deep familiarity with industry practises and the evolution of digital tools. Ethical considerations were rigorously upheld, with informed consent being obtained from all participants and strict adherence to confidentiality guidelines set by the relevant ethics committee; see Blancher (2023) for a detailed description.

DATA COLLECTION

Semi-structured interviews, lasting 40–90 minutes, were conducted between April and June 2023 to explore interoperability challenges, organisational dynamics, and team expertise. These interviews were recorded and transcribed, ensuring accurate data capture and enabling detailed analysis. Participants were anonymised using codes (P01–P14), which are referenced in quotes throughout the findings.

The interview guide comprised 10 open-ended questions across four themes: participant background, productivity challenges, software interoperability, and closing remarks. Designed to align with the research objectives, questions such as 'Can you describe how interoperability challenges have impacted your team's productivity?' encouraged narrative responses (see Blancher (2023) for a detailed list of the research questions). This flexible yet focused format enabled the participants to share in-depth insights whilst allowing new themes to emerge during the discussions (Kvale, 2012).

DATA ANALYSIS

The analysis followed constructivist grounded theory principles through three stages: initial, focused, and theoretical coding (Charmaz, 2014). In the initial coding phase, each interview transcript was examined line by line to identify pertinent segments, allowing themes to organically emerge. This detailed process ensured that subtle, yet significant insights were captured. Through focused coding, the initial codes were then clustered into broader categories, highlighting key patterns such as fragmented alignment, skill development, and organisational innovation. Analytical memos were kept throughout to document evolving thoughts and maintain research reflexivity.

Theoretical coding synthesised these categories into a cohesive framework, which was then contextualised with the existing literature to enhance depth and validity. This iterative process ensured alignment with the study's objectives. It also allowed insights from earlier interviews and coding to shape subsequent data collection, enhancing the depth and relevance of the findings (Corbin & Strauss, 2015).

Several strategies were employed to strengthen the validity of the results, including triangulation and participant validation. Triangulation was achieved by comparing participant insights with the existing literature (Bryman, 2016), and an audit trail of coding decisions was maintained to ensure transparency and critical reflection. To validate the outcome, an additional round of discussions was held with nine participants, confirming that the resulting framework accurately reflected their experiences and perspectives (Creswell & Creswell, 2018).

FINDINGS

It is important to note that the findings presented here are inherently interpretative, consistent with the constructivist grounded theory approach adopted in this study. The interviews revealed an inherent tension felt by design managers. On one hand, they sought managerial and collaboration simplicity through common practises and a shared environment. On the other hand, they emphasised the need for organisational flexibility and specialisation to address project-specific challenges. These opposing expectations illustrate the complex demands on design teams in an ever-changing industry.

From these insights, the AIJ model offers a staged approach to navigate this tension. This model addresses foundational needs whilst fostering agility, providing a pathway to treat simplicity and flexibility as complementary rather than competing goals. The model is presented as a response to the identified challenges and demonstrates how AEC design teams can build the organisational capabilities needed to thrive amidst complex interoperability challenges.

PHASE 1: ALIGNING A FRAGMENTED COLLABORATION

The experiences of design managers highlight a collective struggle to balance disparate practises and tools whilst maintaining functional efficiency. Participants consistently emphasised the challenges of working within fragmented teams, noting how these complexities often led to inefficiencies, miscommunication, and a lack of shared understanding across disciplines and team members. Through these reflections, the importance of establishing a common environment and understanding emerged as central to addressing fragmentation. This phase of the AIJ model represents the initial step in creating alignment and fostering shared practices. The accounts reveal a recurring tension between organisational complexity and management simplicity. Managers described how a shared environment could improve alignment across disciplines by streamlining workflows, centralising data management, and enhancing communication. P14 shared, 'In an ideal scenario, we would all be working in the same vertical stack […] you design something in a particular package, and it can stay in that package for its lifecycle'. Despite this vision, the narratives underscore the practical challenges of achieving such environments. For example, the competing demands of technological advancement and organisational diversity complicate efforts to standardise workflows. P04 expressed frustration with the administrative burden of managing diverse tools, for instance, mentioning the impracticality of 'buying every possible licence on the market for a given project'.

The need for seamless workflows also repeatedly occurred. Managers stressed the importance of tools which integrate smoothly, ensuring consistent data flow and minimising disruptions across project stages. As P05 observed, 'By streamlining processes and reducing manual interventions, teams can focus on core tasks, achieving project goals efficiently'.

Developing a 'Framework for Consistency'

To establish a common environment and understanding, managers described how they developed a framework for consistency as a practical solution. This framework encompassed three key components—standardised workflows, standardised touchpoints, and maintenance of documentation—each serving to address the fragmentation challenges faced by design teams. Standardised workflows emerged as a key strategy for fostering alignment by ensuring repeatable and reliable practises across and within teams. These workflows provided a foundation for maintaining constant quality whilst allowing flexibility to adapt to specific project needs. P04 noted that without such workflows, 'the quality would have been all over the place', with varying approaches leading to uncertainty. Standardised touchpoints added resilience to the system by reducing risks and enhancing accountability. By aligning expectations and defining clear input-output structures, teams could mitigate the risks of disjointed practises, fostering a shared understanding across stakeholders. As P06 explained, having a structured approach 'adds a level of quality and checking rather than it just becoming a black-box'. Maintaining documentation of the processes and encountered issues was seen as another critical strategy for managing fragmentation. Managers emphasised the importance of 'documenting and sharing all [their] processes' to minimise the risks of miscommunication or errors. P07 highlighted the value of maintaining a 'library of scripts for common issues' to provide immediate support and ensure continuity, which can be 'tested and refined' to identify what works effectively and address potential shortcomings. This structured approach streamlined the processes by minimising miscommunication, reducing variability, and simplifying complex interactions.

PHASE 2: BUILDING MASTERY

Building on the alignment established in phase 1, phase 2 of the AIJ focuses on equipping teams with the capabilities to adapt to evolving complexities. As design environments grow increasingly dynamic, the priority shifts from foundational practises to cultivating specialised skills and engendering organisational mastery. This phase involves preparing teams to navigate complexities, leverage diverse tools, and remain agile amidst evolving demands.

Managers consistently highlighted the risks associated with single-vendor dependency. Whilst such reliance offers simplicity and consistency, it constrains adaptability and increases vulnerability to financial risks, such as sudden changes in pricing or licencing models. As P01 responded, 'If [relying] on one vendor, they can change their pricing, and we have no flexibility to pivot'. Conversely, integrating digital tools from multiple vendors introduces inefficiencies, requiring significant coordination to prevent inaccuracies, data loss, or workflow disruptions.

P06 explained, 'The more data moves between systems, the greater the chance of inaccuracies, duplication, or loss'.

The added complexity of ensuring interoperability often leads to frustration and increased and unpredictable workloads, particularly in multidisciplinary projects. As P04 observed, 'We need to spend so much time ensuring systems talk to each other, and even then, there are gaps'. These tensions underscored the need for teams to adopt practises which balanced operational efficiency with creative problem-solving. It was in this context that fostering creativity and innovation emerged as a key strategy.

Fostering Creativity and Innovation

Managers described fostering creativity and innovation as a deliberate organisational strategy to mitigate dependency risks and harness the potential of diverse tools. This involved creating a culture where teams could explore solutions tailored to task-specific challenges without fear of failure. One of the primary ways managers achieved this was through decentralisation and team autonomy. Allowing teams to make localised decisions empowered them to adapt workflows to the unique needs of each project or task. P07 explained this as 'supervising what they're doing, but [ultimately], give them the responsibility'. Identifying and supporting 'super-users' was another critical strategy. These individuals served as in-house experts, guiding their teams through complex interoperability challenges. They acted as hubs of knowledge, helping others troubleshoot issues and explore advanced functionalities of the tools they used. P07 described their impact as 'having go-to people who know the tools inside and out can save hours of troubleshooting and keep the team moving forward'.

Managers also recognised that creativity required time—a resource which often conflicted with short-term productivity goals. They emphasised the importance of securing dedicated time for experimentation, allowing teams to step outside their comfort zone and explore innovative approaches. This time was seen as essential to breaking entrenched practises and fostering innovation. However, as P03 reflected, with 'a lot of companies, […] you need your billing ratio to be high. So, if you want to learn something new, it's often something you have to do in your free time'. By ingraining a culture of creativity and innovation, organisations could navigate complex environments whilst maintaining flexibility. This approach not only addressed immediate challenges but also laid the groundwork for long-term adaptability and resilience.

PHASE 3: REGENERATIVE INNOVATION

The final phase of the AIJ model focuses on building the organisational flexibility and resilience required to navigate VUCA environments. Managers highlighted the increasing complexity of client-imposed requirements and the need to adapt workflows to meet diverse, rapid, and ever-changing expectations and emerging challenges.

These external pressures were compounded by skill gaps within teams, as most managers expressed difficulties getting the relevant skills for their projects, requiring compromises between desired and available resources. As P05 stated, 'You need to understand whether you're really going to be able to get the people to actually do it the way you want it to be done'.

Long-term projects suffer from natural staff turnover or project team variability, causing ongoing skill issues during the project lifetime. Whilst there is a skill shortage for experienced software users, this shortage becomes even more predominant with respect to interoperability skills. Thus, even if teams have people who are extremely skilled in using a tool, they may lack the right skills to translate a model from one discipline to another. As P03 explained, teams create digital models optimised for their needs, and 'you can't translate that to an architectural model because your model is wrong'. Still, P03 acknowledged, 'It's just exactly as correct as I need it to be', reflecting the persistent risks of misalignment.

Building a Community to Distribute Expertise

The evolution of super-users and internal experts, as revealed in the data analysis, has proven invaluable in bridging gaps amongst stakeholders. However, this dynamic also introduces vulnerabilities. P08 warned of 'performance punishment', where individuals excel in a particular area and are subsequently overloaded with similar tasks, leading to stress, demoralisation, and potential attrition. Similarly, P12 cautioned against over-reliance on a few key individuals as they risk becoming 'single points of failure'. This concentration of expertise creates bottlenecks, making organisations susceptible to operational risks. Traditional models often exacerbate this issue by centralising knowledge amongst a select few, underscoring the need for a more distributed approach.

Outcome-focused training offers a solution by democratising expertise and reducing the dependence on singular experts. As P02 noted, the balance between ideal tools and available expertise is critical, underscoring the value of training designed to rapidly achieve specific results. Such training prevents individuals from falling into the 'specialisation trap' (P08) and promotes a broader distribution of skills across teams. P08 further advocated for prioritising community-building over short-term efficiency to mitigate these risks. In the AEC sector, the interplay amongst training, expertise, software proficiency, and organisational success is clear. While in-house expertise is vital, ensuring that it is widespread rather than overly concentrated is the key to fostering resilience and long-term success.

In summary, the AIJ model emerged from the participants' experiences, reflecting a staged process of alignment, mastery, and regenerative innovation. While the Results section has presented these themes descriptively, the following discussion will revisit them to offer deeper analysis and contextualise the findings within the existing literature, in line with the interpretative nature of constructivist grounded theory.

DISCUSSION

This study advances the understanding of how AEC design teams navigate interoperability challenges by proposing the AIJ model. This discussion explicitly links these findings to the existing literature and analyses the emerging theory, demonstrating how the AIJ model builds upon prior work and contributes novel insights.

In the fragmented alignment phase, teams face misaligned practises, disparate workflows, and inconsistent tool adoption. These challenges are well-documented in the literature (Stefanescu, 2020; Wang et al., 2022) and reflect the fragmented project environments where varying levels of digital maturity and differing organisational priorities must be managed (Winfield, 2020). Such misalignments often lead to inefficiencies, communication breakdowns, and duplicated efforts, undermining collaboration. This phase directly addresses RO1, highlighting how design teams experience interoperability challenges in practice. Design managers overcome these issues by establishing frameworks for consistency which align with ISO 19650 guidelines and echo the thinking phase of Michaud et al.'s (2019) approach. These frameworks emphasise standardised workflows, clear information exchange protocols, and thorough documentation to reduce friction caused by diverse tools and practises. ISO 19650 provides a structured foundation for information management, whilst Michaud et al. (2019) offer guidance on mapping current workflows and identifying standardisation opportunities. Ultimately, success in this phase requires cultivating shared mental models and a collective vision (Senge, 2006). Teams must align not only their technical processes but also their understanding of roles and responsibilities. Without such cognitive collaboration, even well-defined processes may fail to resolve underlying miscommunications or disjointed priorities.

During the mastery-building phase, managers confront the limitations of single-vendor solutions and the increasing complexity of multi-tool environments with limited interoperability. Balancing structure with autonomy becomes a priority to navigate these challenges. The participant insights underlined the importance of maintaining this balance, aligning with Sun and Scott's (2005) findings on an individuals' dual needs for control and certainty. Striking the right balance allows team members to develop productive habits and a sense of psychological comfort. This dynamic conforms with Senge's (2006) principle of personal mastery, which encourages individuals to take responsibility for their own learning and growth. This phase also explicitly answers RO2 by examining the strategies teams employ to maintain productivity amidst interoperability challenges.

Additionally, Goodman and Chalofsky (2018) emphasise the value of autonomous learners in driving team development regardless of formal leadership roles. A key enabler in phase 2 is allocating time for exploration and learning. Mistry et al. (2022) note that time away from day-to-day tasks, coupled with a reduction in hierarchical power dynamics, strengthens relationships and supports creativity. In high-complexity environments, Padhee et al. (2023) argue that exploration is critical in avoiding suboptimal solutions. Conversely, failing to balance exploration with the exploitation of known methods can stifle innovation and adaptability. Hall and Hasan (2023) support this view, advocating a hybrid decision-making model which combines centralised guidelines with decentralised experimentation. Such an approach allows organisations to maintain consistent performance whilst encouraging innovation, particularly in projects requiring centralised coordination. In summary, whilst technical frameworks like ISO 19650 offer structural solutions, the findings suggest that organisations must also invest in human-centred competencies. By cultivating individual expertise and team-level capabilities, companies can better address the organisational dimensions of interoperability and position themselves for sustainable adaptability.

Finally, in the regenerative innovation phase, as teams continue to collaborate and accumulate expertise with digital tools, they start discovering improved workflows and interconnections which drive innovation. These advancements are often led by super-users and enable teams to respond creatively to complex problems. However, in a VUCA context of unpredictable client demands and design challenges, over-reliance on a few key individuals presents significant risks. Bottlenecks and operational vulnerabilities arise when critical knowledge is concentrated in only a handful of people, limiting the organisation's flexibility. This phase explicitly addresses RO3, exploring how organisational dynamics, including knowledge distribution, community-building, and training practises, influence the teams' ability to effectively address interoperability issues.

To counter these risks, design managers must prioritise distributing expertise across the team. Viewed through Senge's (2006) team learning lens, this means ensuring that knowledge is shared collectively rather than in isolation, which in turn fosters adaptability and resilience. Implementing outcome-focused training programmes is one practical step in this direction: such training equips team members with the relevant skills needed for current project goals, enabling rapid and goal-orientated learning. Embedding a learning culture which emphasises collaboration and shared understanding further helps teams more effectively navigate turbulent conditions. Rogers's (2003) diffusion of innovations theory illustrates the importance of spreading new ideas from innovators (the super-users) to the broader team. By democratising expertise, organisations mitigate the risks associated with concentrated knowledge and accelerate the uptake of innovative practises. This inclusive approach reduces the dependence on individual experts and nurtures a culture of continuous improvement. In turn, teams become better able to adapt creatively to both external pressures and internal challenges.

Overall, the AIJ model reflects Senge's (2006) principle of systems thinking by providing a holistic, phased approach to interoperability which encompasses organisational factors. Each phase of the model—aligning fragmented collaboration, building mastery, and fostering regenerative innovation—targets specific aspects of team development whilst remaining interconnected. This systems perspective ensures that foundational alignment, individual expertise, and collective adaptability are treated as interdependent elements. In doing so, the AIJ model demonstrates how bridging technical and organisational strategies can build team resilience and drive continuous improvement.

Notably, the AIJ model builds on the foundation of ISO 19650 by explicitly incorporating phased organisational development to address the standard's practical limitations. The model's focus on alignment, mastery, and innovation offers a dynamic roadmap for design teams to address both technical and organisational interoperability challenges. Unlike ISO 19650's emphasis on strict standardisation, the AIJ model prioritises flexibility and iterative learning, allowing teams to balance baseline consistency with creative problem-solving. Michaud et al.'s (2019) phased approach to standardisation closely aligns with the AIJ progression: the thinking phase corresponds to establishing shared understanding in phase 1, the operationalisation stage mirrors the embedding of standard workflows in phase 2, and the diffusion step parallels the spreading of innovative practises in phase 3. By situating the ISO 19650 framework within this broader organisational context, this research highlights the standard's role as a critical enabler of interoperability rather than a standalone solution. Building on the insights from organisational learning frameworks discussed, we identify where adaptive strategies in the AIJ model can enhance ISO 19650's applicability and provide a cohesive approach to organisational innovation and collaboration in the AEC sector (Konopik et al., 2021).

CONCLUSION

Interoperability remains a critical challenge in the AEC sector. This study introduced the AIJ model, derived from design team manager experiences, as a dynamic approach to address interoperability issues with digital tool adoption. Complementing existing interoperability approaches which primarily focus on technical and semantic dimensions, the AIJ model incorporates organisational competencies with iterative learning cycles to help design teams navigate volatile conditions.

By addressing the study's research objectives, the model provides insights into both the challenges design team managers face and the strategies they employ. Specifically, phase 1 of the AIJ model highlights how fragmentation and misaligned workflows disrupt productivity through inconsistent practises, which can be mitigated via developing a framework for consistency. Phase 2 reveals how cultivating super-users whilst allowing decentralised decision-making builds organisational mastery, enabling teams to develop expertise and adapt to multi-tool environments. Phase 3 demonstrates how distributing expertise across teams prevents bottlenecks and vulnerabilities and enables adaptation to volatile conditions.

The study's qualitative focus on UK-based design teams may limit its direct applicability to other contexts but the AIJ model's principles are broadly relevant. By aligning technical and organisational strategies, the model underscores the importance of developing a culture of learning, where design teams invest in organisational skills, iterative feedback loops, and knowledge-sharing mechanisms. For industry adoption, managers are encouraged to balance standardisation with flexibility, ensuring that workflows are robust yet adaptable. Additionally, decentralised decision-making empowers teams to innovate whilst maintaining alignment with the organisational goals. Practitioners should adapt the AIJ model, tailoring it to their organisational contexts to enhance collaboration and innovation in the face of evolving digital complexities.

This research highlights that interoperability challenges require both organisational agility and technical proficiency, positioning the AIJ model as a valuable resource in the evolution towards Construction 4.0. Future research could explore the application of the AIJ model in different organisational contexts to validate its adaptability and further refine its practical implementation.

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