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Digital Twin-Supported Systemic Evolution of Service Design Methods: An Adaptive Framework for Complex Service Ecosystems

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Abstract
The increasing complexity of contemporary service ecosystems has exposed significant limitations in existing Service Design Methods (SDMs), including methodological fragmentation, weak adaptability, limited lifecycle integration, and insufficient responsiveness to dynamic service environments. While Digital Twin (DT) technologies have been extensively applied in manufacturing and operational optimisation, their potential to support adaptive service design and the systemic evolution of SDMs remains underexplored. This study develops and validates a Digital Twin-supported systemic evolution framework for adaptive service ecosystems. Adopting a qualitative Design Science Research (DSR) approach, the study first synthesised the literature and relevant theoretical perspectives to develop a preliminary conceptual framework, which was subsequently validated through expert interviews involving 14 specialists from service design, digital transformation, and DT-related domains. Findings reveal that static procedural structures and inadequate ecosystem coordination capabilities constrain current SDMs. The results further demonstrate that DT technologies can function as adaptive infrastructures that enable real-time synchronisation, predictive analysis, continuous feedback integration, and lifecycle-oriented refinement. The literature synthesis led to the identification of four interconnected mechanisms: real-time adaptive feedback, service ecosystem synchronisation, predictive methodological evolution, and continuous lifecycle refinement, while expert evaluation confirmed their relevance, adaptability, and ecosystem-oriented value, highlighting implementation and scalability considerations. The study contributes theoretically by extending DT applications beyond operational optimisation toward methodological evolution, methodologically by integrating literature-driven framework development with expert validation, and practically by providing organisations with an adaptive framework for intelligent service ecosystem management and continuous service innovation.

Keywords: Digital Twin, Service Design Methods, Service Ecosystems, Adaptive Evolution, Digital Transformation

Introduction

The rapid advancement of digital technologies has fundamentally transformed contemporary service ecosystems, creating increasingly interconnected, data-driven, and adaptive service environments. Organisations across various sectors are experiencing unprecedented levels of complexity due to the integration of intelligent technologies, real-time data infrastructures, and dynamic stakeholder interactions. As a result, service innovation is no longer limited to improving individual service encounters but increasingly involves managing complex socio-technical ecosystems characterised by continuous change and evolving user expectations (Herterich et al., 2023). In such environments, the ability to design, coordinate, and continuously improve services has become a critical organisational capability. Effective service design not only enhances customer experiences and operational efficiency but also supports organisational agility, competitiveness, and long-term sustainability in rapidly changing markets. Consequently, Service Design Methods (SDMs) have become essential tools for understanding user needs, coordinating stakeholder interactions, and facilitating service innovation. However, many existing SDMs remain constrained by fragmented structures, static procedural approaches, and limited adaptability to rapidly changing service environments (Guisan et al., 2025).

The evolution of service design has progressed from traditional process-oriented approaches toward more systemic and ecosystem-oriented methodologies. Earlier service design practices primarily focused on customer touchpoints, operational efficiency, and isolated service improvement initiatives. While these approaches were effective in relatively stable environments, they often struggle to address the increasing complexity of contemporary service ecosystems involving multiple stakeholders, interconnected digital platforms, and real-time decision-making requirements (Tripathi et al., 2024). Modern service environments require methodologies capable of supporting continuous adaptation, ecosystem-wide coordination, and lifecycle responsiveness. Such capabilities are increasingly important because organisations must respond quickly to evolving customer expectations, technological disruptions, and changing market conditions. Consequently, scholars have increasingly emphasised the need for more adaptive and integrated service design approaches capable of responding to dynamic environmental conditions and technological transformations (Das, 2024).

Simultaneously, digital transformation has accelerated the emergence of intelligent service ecosystems supported by technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Digital Twins (DTs). Among these technologies, DT has attracted significant attention due to its ability to create dynamic virtual representations of physical, organisational, and service systems through real-time data synchronisation, simulation, monitoring, and feedback mechanisms (Mohanraj & Balaji, 2026). Originally developed within manufacturing and engineering contexts, DT technology has demonstrated substantial value in predictive maintenance, operational optimisation, and lifecycle management (Duran et al., 2025). More recently, researchers have begun exploring its potential applications in service environments, where continuous adaptation and ecosystem coordination are increasingly critical requirements (Piras et al., 2024). The growing adoption of DT technologies highlights their potential to support smarter, more responsive, and data-driven approaches to service management and innovation.

Despite the growing interest in DT technology, existing research has predominantly focused on technical implementation and operational optimisation. Most studies examine DT applications within manufacturing systems, industrial processes, and cyber-physical infrastructures, with relatively limited attention given to their role in supporting the evolution of service methodologies themselves (Amangeldy et al., 2025). Consequently, there remains a significant gap in understanding how DT capabilities can facilitate the continuous adaptation, refinement, and systemic evolution of SDMs operating within complex service ecosystems. Current service design literature largely concentrates on customer experience enhancement, service innovation processes, and isolated methodological applications rather than the long-term evolution of service methodologies under dynamic ecosystem conditions (Mogaji, 2026). Addressing this gap is important because organisations increasingly require adaptive service design approaches that can effectively leverage real-time data, predictive intelligence, and ecosystem-wide coordination to maintain service relevance and competitiveness.

Furthermore, contemporary service ecosystems are increasingly characterised by interconnected stakeholders, continuous data exchange, and rapidly changing contextual conditions, all of which challenge conventional service design approaches. Existing SDMs often lack mechanisms for integrating real-time feedback, predictive insights, and adaptive decision-making processes necessary for maintaining methodological relevance over time (Hoffmann et al., 2025). The absence of structured mechanisms for continuous methodological evolution reduces the capacity of organisations to respond effectively to emerging service challenges and opportunities. This limitation highlights the need for a more integrated framework capable of supporting adaptive service design through intelligent technological infrastructures. Such a framework is particularly important for organisations seeking to improve service responsiveness, enhance stakeholder collaboration, optimise resource utilisation, and support continuous innovation within increasingly complex service ecosystems.

Drawing upon Service-Dominant Logic (S-D Logic), Service Ecosystem Theory, Task–Technology Fit (TTF), and Design Science Research (DSR), this study investigates the role of DT technologies in supporting the systemic evolution of SDMs. S-D Logic emphasises value co-creation through interactions among multiple actors and resources within service ecosystems (Jaakkola et al., 2024), while Service Ecosystem Theory conceptualises service environments as dynamic and interconnected systems characterised by continuous adaptation and resource integration (Pan et al., 2025). TTF further provides a theoretical basis for examining the alignment between DT capabilities and the adaptive requirements of service design activities (Vafaei-Zadeh et al., 2026). Together, these theoretical perspectives provide a robust conceptual foundation for synthesising the existing literature and developing a DT-supported framework capable of supporting adaptive service design and continuous methodological evolution within complex service ecosystems.

Building upon these theoretical perspectives and the identified research gaps, this study conceptualises a preliminary DT-supported systemic evolution framework through a synthesis of the literature on service design, digital transformation, and intelligent service ecosystems. The framework integrates the adaptive capabilities of DT technologies with the evolutionary requirements of SDMs, proposing four interconnected mechanisms: real-time adaptive feedback, service ecosystem synchronisation, predictive methodological evolution, and continuous lifecycle refinement. Rather than viewing DT solely as a technological tool for operational optimisation, the framework positions DT as an adaptive infrastructure that supports the continuous evolution of service design practices across dynamic ecosystem contexts.

The significance of this study lies in its potential to bridge the gap between DT capabilities and service design evolution. By integrating digital twin technologies with service design theory, the study provides a structured approach for supporting adaptive service innovation, ecosystem coordination, and continuous methodological refinement. The proposed framework is expected to benefit service designers, innovation managers, digital transformation practitioners, organisational leaders, and policymakers who are responsible for managing complex service ecosystems. Moreover, the framework offers practical guidance for enhancing organisational adaptability, strengthening stakeholder collaboration, improving data-driven decision-making, and supporting sustainable service innovation in digitally transformed environments.

Therefore, this study aims to develop and validate a DT-supported systemic evolution framework for adaptive service ecosystems. Specifically, the study seeks to identify the key challenges affecting contemporary SDMs, synthesise theoretical and literature-based insights into an integrated conceptual framework, and evaluate its relevance and applicability through expert perspectives regarding the role of DT technologies in service design evolution. By extending DT applications beyond operational optimisation toward methodological evolution, the study contributes to the growing body of knowledge on adaptive service innovation and intelligent service ecosystem management.

The findings are expected to provide theoretical contributions by expanding the conceptual understanding of DT-enabled service evolution, methodological contributions through the development and expert validation of a structured evolution framework, and practical contributions by offering organisations a strategic approach for enhancing service adaptability and ecosystem responsiveness in digitally transformed environments. Ultimately, the study contributes to the development of more resilient, intelligent, and adaptive service ecosystems capable of responding effectively to the challenges and opportunities of ongoing digital transformation.

Literature Review

The increasing complexity of contemporary service ecosystems has significantly transformed the role of SDMs. Traditionally, SDMs focused on improving customer experiences, service processes, and organisational efficiency through structured and user-centred approaches. However, the rapid digitalisation of service environments has introduced new challenges associated with interconnected stakeholders, real-time data flows, and dynamic ecosystem interactions (Lin et al., 2025). Consequently, scholars have argued that conventional SDMs are often insufficient for addressing the adaptive requirements of modern service systems due to their fragmented structures, limited interoperability, and static procedural characteristics.

Recent developments in service research have emphasised the transition from isolated service interventions toward ecosystem-oriented service design approaches. Service ecosystems consist of multiple actors, technologies, institutions, and resources that continuously interact to co-create value (Kilinc et al., 2025). Within such environments, service methodologies must support ongoing adaptation, stakeholder coordination, and lifecycle responsiveness. However, existing SDMs frequently lack mechanisms for continuous refinement and real-time responsiveness, reducing their effectiveness in increasingly complex service contexts. This limitation highlights the need for more adaptive and evolution-oriented approaches capable of supporting long-term service innovation.

DT technology has emerged as a promising solution for addressing these challenges. DT refers to a dynamic digital representation of physical or service systems that continuously interacts with real-world environments through data synchronisation, simulation, monitoring, and feedback processes (Mohanraj & Balaji, 2026). Originally developed for manufacturing and engineering applications, DT technology has demonstrated significant capabilities in predictive analytics, operational optimisation, and intelligent decision-making. More recently, researchers have begun exploring its potential application in service ecosystems, where real-time monitoring, adaptive responses, and ecosystem-wide coordination are increasingly important.

S-D Logic, Service Ecosystem Theory, and TTF inform the theoretical foundation of this study. S-D Logic views value as co-created through interactions among multiple actors rather than produced solely by service providers (Torvinen et al., 2026). This perspective emphasises resource integration, collaboration, and continuous value creation within service ecosystems. Similarly, Service Ecosystem Theory conceptualises services as dynamic systems composed of interconnected actors and institutional arrangements that continuously evolve through adaptive interactions. These theories provide a conceptual basis for understanding SDMs as evolving ecosystem components rather than static procedural tools.

Additionally, TTF theory suggests that technological effectiveness depends on the degree of alignment between technological capabilities and task requirements (Thanthrige et al., 2025). In the context of this study, DT technologies offer functionalities such as real-time feedback, predictive simulation, and adaptive decision support that align closely with the evolutionary requirements of contemporary SDMs. Therefore, integrating DT capabilities into service design processes may facilitate continuous methodological adaptation, ecosystem coordination, and lifecycle refinement. Collectively, S-D Logic, Service Ecosystem Theory, and TTF provide complementary perspectives that explain how DT capabilities can be aligned with the adaptive needs of service design, thereby offering a robust theoretical foundation for developing a DT-supported service design framework (Figure 1).

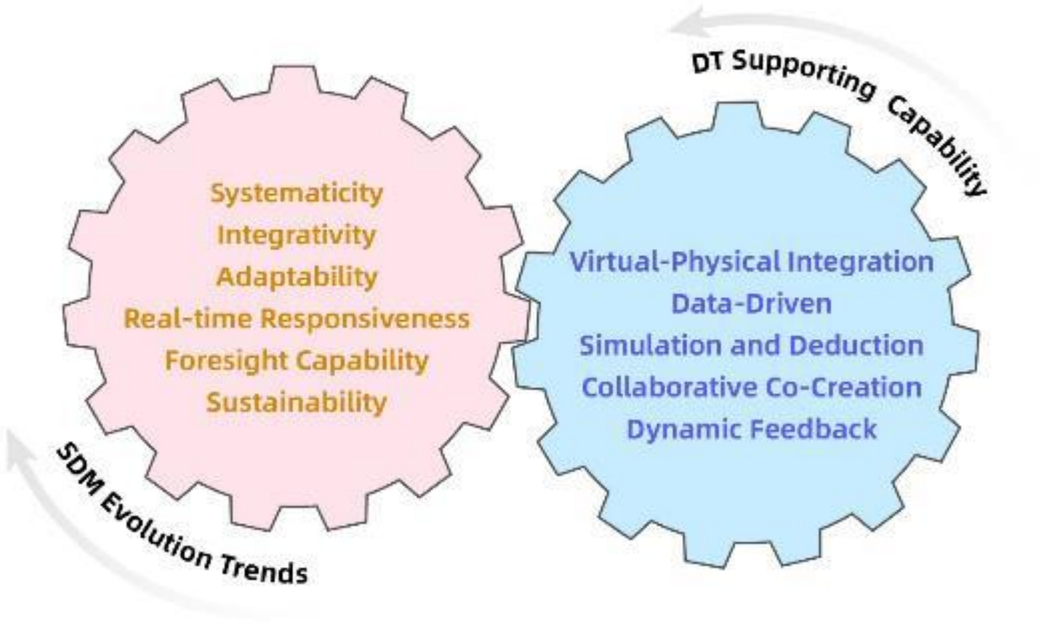

Figure 1. Preliminary DT Support Mechanism Derived from the Literature

Conceptual Framework for DT-Supported Service Design

Synthesising the reviewed literature reveals that contemporary SDMs require mechanisms that extend beyond static process improvement and support continuous adaptation within dynamic service ecosystems. Existing studies consistently highlight the importance of real-time information exchange, stakeholder integration, predictive decision-making, and lifecycle-oriented management in enabling sustainable service innovation (Kilinc et al., 2025; Mohanraj & Balaji, 2026). At the same time, the capabilities inherent in DT technologies—including data synchronisation, simulation, monitoring, and intelligent feedback—closely correspond to these emerging service design requirements.

Drawing upon the complementary insights of S-D Logic, Service Ecosystem Theory, and TTF, this study synthesises the literature into a preliminary DT-supported systemic evolution framework (Figure 2). The framework conceptualises DT not merely as an operational optimisation tool, but as an adaptive digital infrastructure that enables the continuous evolution of SDMs through four interrelated mechanisms: (1) real-time adaptive feedback, (2) service ecosystem synchronisation, (3) predictive methodological evolution, and (4) continuous lifecycle refinement. These mechanisms collectively facilitate the integration of dynamic ecosystem data, stakeholder collaboration, predictive intelligence, and iterative service improvement, thereby supporting more adaptive and resilient service design practices.

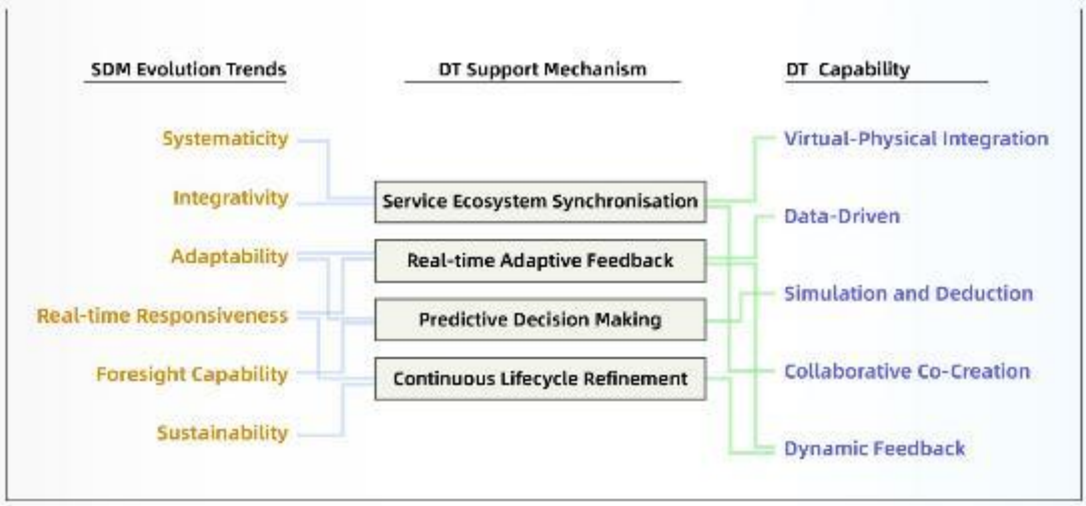

Figure 2. Literature-Derived Conceptual Framework for DT-Supported Service Design

Based on the reviewed literature, a significant research gap remains regarding how DT technologies can systematically support the evolution of SDMs beyond operational optimisation. Although previous studies have examined DT implementation and service innovation independently, limited attention has been given to integrating these perspectives into a unified conceptual framework for adaptive service design. Accordingly, this study addresses the identified gap by developing a literature-driven DT-supported systemic evolution framework and subsequently validating its relevance and applicability through expert evaluation. This approach contributes to advancing knowledge on the role of DT technologies in enhancing adaptability, responsiveness, and continuous improvement within complex service ecosystems.

Methodology

This study adopted a qualitative research approach within the DSR paradigm to investigate how DT technologies can support the systemic evolution of SDMs. DSR was selected because it provides a structured process for developing and evaluating innovative artefacts that address complex real-world problems while simultaneously contributing to theoretical knowledge (Antony et al., 2024). In this study, the primary artefact was a DT-supported systemic evolution framework designed to enhance the adaptability and continuous refinement of SDMs within complex service ecosystems. Following the principles of DSR, the research was conducted in two sequential phases: (1) the development of a preliminary conceptual framework through the synthesis of the literature and relevant theoretical perspectives, and (2) the validation and refinement of the proposed framework through expert evaluation.

The preliminary framework was constructed based on the findings of the literature review, integrating insights from Service-Dominant Logic, Service Ecosystem Theory, and Task–Technology Fit theory with the identified capabilities of DT technologies in adaptive service environments. This process enabled the conceptualisation of a DT-supported framework that links real-time data synchronisation, ecosystem coordination, predictive decision-making, and lifecycle management with the evolving requirements of contemporary SDMs.

Data for the framework validation stage were collected through semi-structured expert interviews involving 14 experts from academia and industry. Participants were selected using purposive sampling based on their expertise in service design, digital transformation, DT technologies, systems thinking, and innovation management. This approach ensured that participants possessed relevant knowledge and practical experience related to adaptive service ecosystems and emerging digital technologies. Rather than generating the framework itself, the interviews were designed to evaluate the conceptual relevance, completeness, practicality, and applicability of the literature-derived framework while also eliciting recommendations for its refinement.

The interview protocol was developed based on findings from the earlier stages of the research, including the synthesis of SDM trends, challenges, and the preliminary framework components identified through the literature review. To enhance validity and reliability, a pilot interview was conducted prior to the formal data collection process. All interviews were recorded, transcribed, and analysed using thematic analysis. The analysis followed an iterative coding process involving data familiarisation, open coding, category development, and theme generation. This approach enabled the identification of recurring patterns and expert perspectives regarding the suitability and implementation of DT-enabled service evolution mechanisms.

To strengthen the trustworthiness of the findings, several quality assurance strategies were employed, including expert triangulation, member verification, and systematic documentation of analytical decisions. The themes generated through the expert evaluation process were used to assess and refine the preliminary framework, particularly with respect to its relevance, adaptability, feasibility, and practical applicability within contemporary service ecosystems. The validation findings confirmed the importance of four interconnected mechanisms—real-time adaptive feedback, service ecosystem synchronisation, predictive methodological evolution, and continuous lifecycle refinement—which together constitute the validated DT-supported systemic evolution framework proposed in this study.

Results and Discussion

The expert evaluation findings indicate that contemporary SDMs face significant challenges in adapting to increasingly complex and digitally enabled service ecosystems. Participants consistently confirmed three major issues identified in the literature: methodological fragmentation, weak adaptability, and lifecycle disconnection. These challenges limit the ability of organisations to coordinate stakeholders, respond to dynamic environmental changes, and continuously evolve service offerings. Such findings support previous studies that have highlighted the limitations of traditional service design approaches in managing interconnected and data-driven service environments (Mohanraj & Balaji, 2026).

The experts emphasised that many SDMs have been developed independently across disciplines and industries, resulting in inconsistent structures and limited interoperability. Furthermore, fixed procedural workflows often lack the flexibility required to adapt to rapidly changing ecosystem conditions. Another recurring concern was the absence of mechanisms that facilitate continuous coordination across different stages of the service lifecycle, which reduces long-term responsiveness and innovation capability. These observations provide empirical support for the challenges identified during the literature synthesis and reinforce the need for a more adaptive DT-supported service design framework (Table 1).

Table 1
Key Challenges Affecting Contemporary Service Design Methods

Challenge	**Description**
Methodological Fragmentation	Independent development of SDMs across domains reduces integration and interoperability.
Weak Adaptability	Fixed procedural workflows struggle to respond to changing ecosystem conditions.
Lifecycle Disconnection	Limited coordination across service lifecycle stages hinders continuous evolution.

The validation of these challenges demonstrates that existing SDMs are insufficiently equipped to support adaptive service ecosystems. As service environments become increasingly interconnected and data-intensive, organisations require more dynamic and responsive methodologies capable of facilitating continuous learning and adaptation (Kilinc et al., 2025). The consistency between the literature review and expert perspectives provides further justification for the preliminary conceptual framework proposed in this study.

In evaluating the proposed framework, experts highlighted the transformative potential of DT technologies for supporting adaptive service design. Participants consistently described DT as more than a technological monitoring tool, emphasising its ability to function as an adaptive infrastructure that enables continuous service evolution. In particular, the experts confirmed the importance of three core DT capabilities identified through the literature review: real-time adaptation, predictive capability, and ecosystem coordination. These capabilities enable organisations to synchronise service operations with changing environmental conditions, anticipate future scenarios, and improve coordination among diverse stakeholders.
The expert perceptions of DT capabilities and their contributions to service design evolution are presented in Table 2.

Table 2
DT Capabilities Supporting Service Design Evolution

DT Capability	Contribution to SD Evolution
Real-Time Adaptation	Enables continuous synchronisation and immediate response to ecosystem changes.
Predictive Capability	Supports scenario simulation and proactive methodological refinement.
Ecosystem Coordination	Provides integrated visibility across stakeholders, processes, and technologies.

The findings indicate that DT technologies can significantly enhance the adaptability and responsiveness of SDMs by enabling continuous feedback integration and predictive decision-making. More importantly, the expert evaluation confirmed the conceptual relevance and practical applicability of the preliminary DT-supported systemic evolution framework developed through the literature synthesis. The experts agreed that the framework appropriately captures the essential mechanisms required to support adaptive service ecosystems and recognised the value of integrating DT capabilities with service design processes.

The validation process further reinforced the importance of the framework's four interconnected mechanisms: real-time adaptive feedback, service ecosystem synchronisation, predictive methodological evolution, and continuous lifecycle refinement (Figure 3). Rather than introducing new conceptual dimensions, the expert insights largely corroborated the literature-derived structure while providing practical recommendations regarding implementation, organisational readiness, and scalability. Consequently, the preliminary framework was refined and validated as a comprehensive model for supporting the continuous evolution of SDMs within digitally transformed service ecosystems.

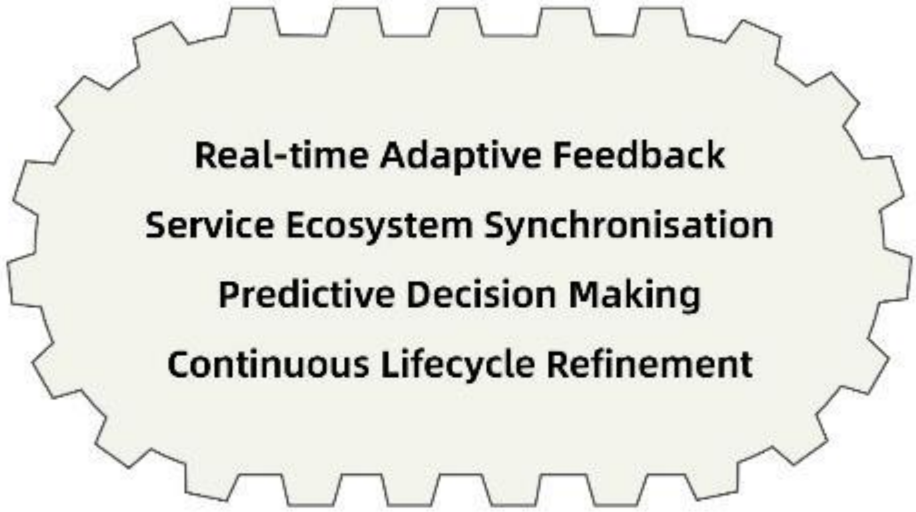

Figure 3. Validated DT-Supported Systemic Evolution Framework

From a theoretical perspective, these findings extend existing DT literature by demonstrating that DT technologies can facilitate methodological evolution rather than merely operational optimisation (Duran et al., 2025). The results also reinforce the principles of Service-Dominant Logic and Service Ecosystem Theory, which emphasise value co-creation, resource integration, and adaptive interactions among ecosystem actors (Jaakkola et al., 2024). The alignment between the literature synthesis and expert evaluation further supports the integration of these theoretical perspectives in explaining how DT technologies can enable adaptive service design.

Practically, the validated framework provides organisations with a structured approach for integrating real-time feedback, predictive analytics, ecosystem coordination, and lifecycle management into service design processes. Nevertheless, experts noted that successful implementation requires strong organisational readiness, effective data governance, interoperability standards, and scalable digital infrastructures (Figure 4). These considerations highlight that both technological and organisational capabilities are essential for achieving sustainable service evolution in contemporary service ecosystems.

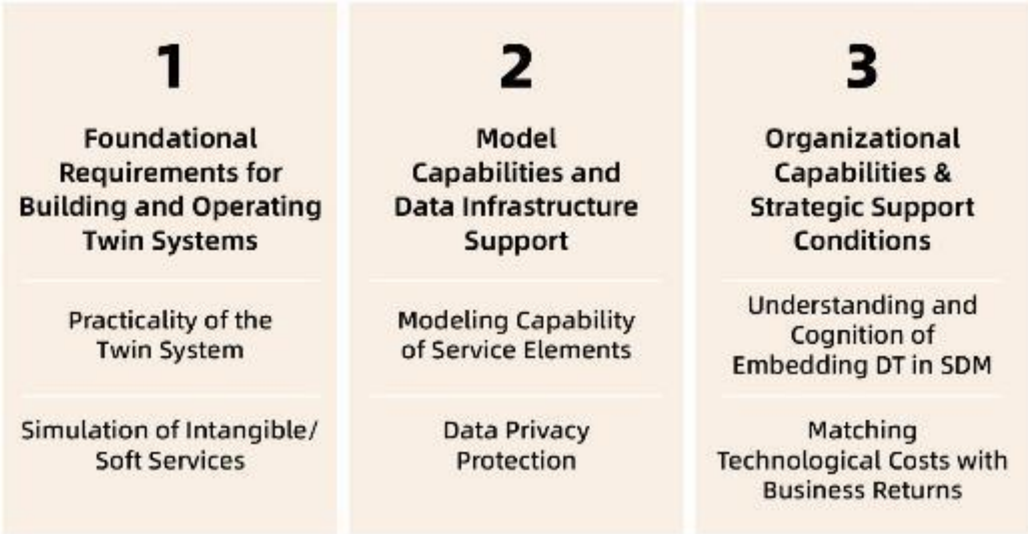

Figure 4. Key Prerequisite Conditions for DT-Supported Service Design Implementation

Conclusion

This study investigated the role of DT technologies in supporting the systemic evolution of SDMs within increasingly complex and digitally transformed service ecosystems. The findings revealed that existing SDMs continue to face significant challenges, particularly methodological fragmentation, limited adaptability, and weak lifecycle integration. These limitations reduce the ability of organisations to respond effectively to dynamic stakeholder needs, real-time data environments, and evolving service conditions.

Drawing upon the synthesis of the literature and the integration of relevant theoretical perspectives, this study developed a preliminary DT-supported systemic evolution framework to address these challenges. The framework conceptualises DT technologies as adaptive infrastructures capable of facilitating continuous service evolution through four interconnected mechanisms: real-time adaptive feedback, service ecosystem synchronisation, predictive methodological evolution, and continuous lifecycle refinement. The subsequent expert evaluation further validated the relevance and applicability of these mechanisms, confirming that DT capabilities such as real-time synchronisation, predictive analytics, and ecosystem-wide coordination can support more responsive and adaptive service design practices.

The study contributes to the literature by extending the application of DT beyond operational optimisation toward the continuous evolution of service methodologies. Methodologically, it demonstrates the value of integrating literature-driven framework development with expert validation within a DSR approach. Practically, the validated framework provides organisations with structured guidance for enhancing service adaptability, stakeholder coordination, and data-driven decision-making in increasingly complex service ecosystems.

Despite its contributions, the study is limited by its qualitative and expert-based validation approach. Although the framework was conceptually developed from the literature and validated through the perspectives of 14 domain experts, further empirical investigation is required to examine its implementation across different service sectors and organisational contexts. Future research should therefore test and refine the proposed framework using case studies, longitudinal investigations, or quantitative validation methods to further establish its effectiveness, scalability, and generalisability in supporting adaptive service ecosystems.

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