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Digital twins: a game changer in customer experience

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Abstract

Purpose – Digital twins have been employed in engineering, agriculture, manufacturing, information systems, computer science and digital medicine. This article introduces digital twins to the services and customer experience (CX) literature, addressing complex challenges in CX management. Unlike traditional software tools that rely on static dashboards or front-end interfaces that merely display descriptive statistics or historical data, a CX digital twin integrates real-time data streams with simulation capabilities to anticipate emerging issues and dynamically test potential intervention strategies. We present a conceptual framework for CX digital twins, provide a practical roadmap, and demonstrate its applicability across three diverse service settings: heavy asset B2B shipping service, retail food service and healthcare.

Design/methodology/approach – This article takes a conceptual approach and draws insights from literature in engineering, manufacturing, information systems and computer science.

Findings – CX has traditionally been managed reactively, addressing complaints after service has concluded. We advance CX management by integrating journey mapping with dynamic, real-time inputs, allowing for proactive issue resolution, opportunity identification and experience reconfiguration through digital twins. We position CX digital twins as a transformative proactive approach, which recasts CX management to a focus on predicting and intervening in contrast to attempting to address problems only after customers report them. The article concludes with directions for future research.

Practical implications – We provide a novel approach to CX management with a clear, actionable roadmap. Practically, our five-step roadmap (AAICE) enables organizations to implement CX digital twins by: (1) Assessing their operational environments to uncover inefficiencies, customer pain points and service challenges, thereby anticipating potential problems through advanced data-driven insights before they occur. (2) Analyzing historical, real-time and synthetic data flows to optimize operations and enhance CX and proactively intervening to resolve issues before they escalate, using predictive analytics and real-time monitoring. (3) Identifying opportunities to delight customers by personalizing touchpoints, such as tailoring product recommendations or providing timely support. (4) Co-designing innovative customized service offerings through simulated customer scenarios, enabling organizations to optimize processes and innovate. (5) Evaluating the effectiveness of CX digital twin implementation using sound CX and operational metrics and tools refining systems based on feedback and driving continuous improvement to deliver seamless and superior CXs.

Originality/value – This article is the first to introduce the concept of digital twins in CX management. We provide a novel approach to thinking about CX through our innovative CX digital twins conceptual framework comprising four dimensions: the asset, data exchange, digital replica (agents) and feedback loop. Further, we offer a practical roadmap (AAICE) for implementation and provide directions for future research.

Keywords Customer experience, Artificial intelligence, Customer experience management, Digital twins

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1. Introduction

Customer experience (CX) is a cornerstone of organizational success, shaping customer satisfaction, loyalty, revenue and even employee satisfaction (Rawson *et al.*, 2013). CX encompasses interactions customers have with an organization, whether human or machine-based, spanning the entire customer journey – before, during and after purchase (Lemon and Verhoef, 2016), such that every interaction matters (McColl-Kennedy *et al.*, 2019). While Pine and Gilmore (1999) advocate for organizations to strive to provide extraordinary experiences, Heinonen and Lipkin (2023) highlight that the everyday experiences, which comprise the bulk of customers' lives, offer perhaps the greatest potential for both customers and business performance.

So, whether organizations seek to provide extraordinary service experiences, or positive experiences in the more mundane, CX is important to both organizations and customers. Accordingly, considerable attention has been devoted to conceptualizing (Lemon and Verhoef, 2016; Becker and Jaakkola, 2020), measuring (Villarroel Ordenes *et al.*, 2014; Rahman *et al.*, 2022), and managing the CX (Macdonald *et al.*, 2016; McColl-Kennedy *et al.*, 2019).

Traditional CX management often relies on reactive approaches, addressing problems only after customers report them. These strategies frequently center on singular outcome metrics, such as customer lifetime value (CLV) or Net Promotor Score (NPS), which fail to capture the complexity and dynamism of modern customer interactions (see, for example, Rust *et al.*, 2004; Keiningham *et al.*, 2007). We depart from this reactive approach by providing a proactive approach, introducing digital twin technology in CX, which recasts customer experience management to a focus on predicting and intervening, thus avoiding or at least reducing negative consequences. Building on key digital twin definitions, for example Grieves and Vickers (2017), Katsoulakis *et al.* (2024), and Lim, Zheng and Chen's (2020) thorough review of the digital twin literature, we propose the following definition: "A CX digital twin is a virtual model of a service system or process that reflects real-time operations, enabling businesses to monitor, simulate and predict outcomes, facilitating proactive adjustments to improve the experience." For example, a digital twin of a healthcare service can predict delays in real time, allowing the organization to address problems *before* they impact healthcare customers. Unlike traditional software tools that rely on static dashboards or front-end interfaces that merely display descriptive statistics or historical data, a CX digital twin integrates real-time data streams with simulation capabilities to anticipate emerging issues and dynamically test potential intervention strategies. This predictive functionality transforms the role of digital technologies in service management from passive monitoring to active orchestration of the CX.

Our CX digital twin conceptual framework comprises four dimensions. The *asset* dimension encompasses not only physical equipment and facilities but also human processes, technological systems, and social interactions that shape the service encounter. The *data exchange* dimension captures how historical, real-time and synthetic data flow between the physical service and its digital counterpart. The *digital replica (agents)* dimension refers to the virtual model and its capabilities for modeling, predicting, simulating, visualizing, intervening and reconfiguring the service system. Finally, the *feedback loop* dimension completes the system by continuously feeding insights from the digital replica back to the physical service, enabling learning and adaptation over time. By integrating these dimensions, digital twins transform CX management from a static, retrospective practice to an anticipatory, co-creative process.

Intervening and limiting or resolving the problem, even without the customer's awareness, is central to this proactive approach. We adopt Kozlenkova *et al.* (2024)'s recommended conceptual framework development process, beginning by first identifying a critical industry challenge: most CX systems remain largely reactive, relying on historical data and lagging indicators to address customer pain points only *after* they occur.

Second, we propose a fundamental shift in CX management – from retrospective diagnosis (e.g. Bitner, 1992; Bitner *et al.*, 2008) to real-time, predictive orchestration. We build on and extend existing CX management by integrating customer journey mapping (e.g. Lemon and

Verhoef, 2016; McColl-Kennedy *et al.*, 2019) with dynamic, context-aware inputs across time and space. This enables organizations to anticipate service issues before they occur, discover latent opportunities and redesign experiences proactively. By leveraging historical, simulated and synthetic data through digital twin technologies, firms can co-design new offerings, iterate on service configurations and deliver personalized interventions at scale. This represents a conceptual innovation in CX – a game-changing move from managing experiences reactively to configuring them proactively to prevent negative outcomes.

Third, we build our conceptual framework by synthesizing constructs primarily from manufacturing and technology literature and applying them to CX contexts (e.g. Lee *et al.*, 2020; Liu *et al.*, 2021). We offer our innovative conceptual framework which is comprised of four components: (1) the asset which is made up of physical, process, technology systems and social elements, (2) data exchange comprised of historical, real-time and synthetic data, (3) the digital replica (agents) comprised of modeling, predictions, simulations, visualization, intervention actions, reconfiguration and innovation, and (4) a feedback loop comprised of past events, the moment of truth and future states. By integrating principal–agent (PA) theory (Jensen and Meckling, 1976) into the CX digital twins conceptual framework, we show how digital twin systems redefine agency, redistribute power and reduce oversight costs in service ecosystems. The feedback loop fosters dynamic accountability by enabling real-time monitoring and proactive interventions. Data exchange empowers principals with actionable insights, fostering greater collaboration and transparency. Finally, we provide a five-step actionable roadmap (AAICE) to implement CX digital twins and offer directions for future research.

2. What we know and what we need to know about managing CX in a digital world

2.1 Managing CX

Managing the CX has focused on addressing problems *after* they arise. Furthermore, organizations have traditionally relied on single metrics, such as CLV or NPS (Rust *et al.*, 2004; Keiningham *et al.*, 2007). However, as Lemon and Verhoef (2016) argue, these retrospective, aggregate metrics fail to capture the complexity of the customer journey, where experiences unfold across multiple, dynamic and interdependent touchpoints. The use of such traditional modeling techniques may lead to misinformed decisions, including the inability to identify customers at risk of defection or to anticipate declining engagement (McColl-Kennedy *et al.*, 2019). This emphasizes the need for more predictive, data-driven and context-aware approaches, such as digital twin technology, that can anticipate issues in real-time and enable proactive experience design and intervention.

Unlike traditional software, such as dashboards, that do not have the capabilities to identify problems early and act on them before they become CX problems, CX digital twins can identify problems and opportunities *before* they arise, then intervene and reconfigure to enhance the CX across different contexts in space and time.

Research across various domains such as engineering, manufacturing, healthcare and smart cities has demonstrated the transformative potential of digital twins. Originally conceptualized in manufacturing to optimize product lifecycle management (Grieves and Vickers, 2017), digital twins provide a real-time, virtual representation of physical systems, enabling monitoring, simulation capabilities and intervention before problems escalate. Digital twins have been deployed in healthcare to model and predict patient health outcomes, thus enhancing preventive care (Katsoulakis *et al.*, 2024). Similarly, in smart cities, digital twins simulate traffic flows and environmental conditions, optimizing resource use and enhancing urban planning (Liu *et al.*, 2021).

In the realm of CX management, research has begun to explore applying digital twin technology to service systems. Initial studies show how digital twins can enhance operational efficiency by predicting and mitigating service failures (Bolton *et al.*, 2018). For example, in heavy asset B2B services like shipping, digital twins can predict equipment performance to resolve issues preemptively, minimizing service interruptions (Kowalkowski *et al.*, 2023). This predictive capability is particularly relevant for service organizations seeking to provide seamless, high-quality experiences over time.

A key advancement in CX management, facilitated by digital twins, is the ability to intervene in real-time based on continuous feedback loops (McColl-Kennedy *et al.*, 2019). By integrating data from multiple sources – historical, real-time and synthetic – digital twins provide a holistic view of the customer journey, enabling more predictive and proactive and personalized interventions. Unlike traditional software, which is not designed to have predictive capabilities, recommending resolution and acting autonomously in specific scenarios. This is a significant departure from traditional service recovery models relying on simple CX dashboards that only address issues after they occur, typically when customers complain to the service provider that they are not satisfied with the outcome and/or with the way they were treated by the organization often through justice theory-based frameworks focusing on distributive, procedural and interactional justice (Sparks and McColl-Kennedy, 2001; McColl-Kennedy *et al.*, 2003).

Yet, much remains to be done. First, we lack a comprehensive understanding of how digital twins can be leveraged to co-create value with customers through real-time interactions. To address this problem, we conceptualize how digital twins can proactively identify and mitigate potential issues in the CX to prevent negative outcomes. Second, while we have CX metrics such as CLV and NPS (Rust *et al.*, 2004; Keiningham *et al.*, 2007), new technologies such as digital twins are needed to capture the dynamic, multi-faceted complexity of customer interactions. Third, the ethical implications of using digital twins in CX management are underexplored. How do we balance the benefits of personalized CX, real-time interventions with concerns about privacy, data security and the potential for over-surveillance?

We must consider the human dimension in the CX digital twins application. Service research suggests that customers value relational interactions as much as technical efficiency (Heinonen and Lipkin, 2023). Therefore, digital twins should not only anticipate and resolve technical failures, but they should also potentially facilitate deeper emotional connections between customers and organizations. This aligns with the emerging focus on holistic CX management, where technology complements rather than replaces human touchpoints. In short, managing CX in a digital world requires a mindset shift for organizations from reactive to proactive management, facilitated by CX digital twins.

2.2 What are digital twins?

Digital twins, while gaining considerable popularity in this era of artificial intelligence (AI) and Industry 4.0, have foundations in a range of different disciplines, including production engineering, aerospace engineering, and product life cycle management. The concept was first introduced at a University of Michigan presentation for the development of the Product Lifecycle Management (PLM) Centre in 2002 (Grieves and Vickers, 2017) and received its current name “Digital Twins” from NASA in 2010 (Piascik *et al.*, 2010).

The Apollo program is often cited as one of the first practical applications of digital twins (Niederer *et al.*, 2021). NASA used ground-based simulators that replicated the systems deployed in space, a virtual counterpart mostly used for training purposes. During the Apollo 13 mission, when a critical explosion damaged the spacecraft’s primary engine, NASA mission control used real-time data from the spacecraft to evaluate scenarios and guide the decision-making process, ultimately contributing to the astronauts’ safe return. Grieves and Vickers (2017) went on to define digital twins as a set of virtual information constructs that fully describe a potential or actual physical manufactured product from the micro-atomic level to the macro geometrical level (Table 1). The last five years have seen rapid development of the concept of digital twins across multiple industries and fields, resulting in different perspectives, contexts and definitions. Table 1 provides illustrative examples of definitions across a range of disciplines.

Digital twins have evolved significantly since their early conceptualization in production and aerospace engineering. Initially developed for Product Lifecycle Management (PLM), their scope now extends far beyond engineering, finding applications across industries such as healthcare, agriculture, and urban planning. This versatility has been driven by advancements in AI, Internet of Things (IoT) and real-time data integration.

Digital twins differ fundamentally from traditional tools such as simulations, dashboards and static journey maps in several important ways. First, while simulations are typically scenario-based models run offline to explore hypothetical outcomes, digital twins are live, continuously updated virtual replicas of service systems that evolve in real time. Second, unlike dashboards, which provide historical or descriptive analytics and static KPIs, digital twins enable predictive and prescriptive decision-making, offering not just visibility into what is happening, but also foresight into what might happen and how to intervene effectively. Third, moreover, dashboards are often limited to visualizing fragmented metrics (e.g. NPS, CLV) without linking them to underlying system behaviors. In contrast, digital twins integrate real-time, historical and synthetic data to simulate complex interactions between people, processes and technologies. They support closed-loop feedback, allowing organizations to model, test, and refine interventions before implementing them in the real world, something dashboards or traditional business intelligence tools cannot do. In essence, digital twins transform CX management from a passive, descriptive process into a proactive, adaptive system of experience orchestration, offering firms a new level of control, personalization and responsiveness.

2.3 Multidisciplinary applications of digital twins

Digital twins are increasingly recognized as transformative tools across multiple disciplines and industries (Liu *et al.*, 2021; Iliuţă *et al.*, 2024; Sun *et al.*, 2024; Toubia *et al.*, 2025). Enabled by the rapid progression of associated technologies such IoT, multi-physical simulation and real-time sensors and sensor networks, efforts in the digital twin technology for manufacturing, heavy asset and Architecture, Engineering, Construction, and Operation (AECO) industries has become prevalent over the last decade (Tao *et al.*, 2019; Jones *et al.*, 2020, Liu *et al.*, 2021). The value of digital twins is being leveraged by both researchers and enterprises alike due to this alignment of digital twins with contemporary requirements of smart manufacturing and Industry 4.0, with more than 1,000 institutions (Tao *et al.*, 2024) and enterprises such as Siemens, Tesla, ANSYS, GE, PTC, Dassault and other global well-known enterprises (Wang *et al.*, 2022) executing both implementation and application of digital twins in their respective fields. From innovation and realization of rapid engineering design (Lo *et al.*, 2021) to infrastructure operation and maintenance, facilitating the integration of multi-domain data, addressing challenges such as data heterogeneity and interoperability, thereby improving decision-making and collaboration with accurate and timely data (Liu *et al.*, 2021; Toubia *et al.*, 2025). Application to real-time monitoring of production processes (Pei *et al.*, 2021) and asset and complex system prognostic and health management is also occurring (Ahmad *et al.*, 2023; Toothman *et al.*, 2023).

Digital Twins for Health (DT4H) is emerging as a transformative technology in healthcare, due to the ability to integrate major stakeholders with the healthcare sector, such as government, IT and AI industries (Katsoulakis *et al.*, 2024), while offering opportunities for innovations like personalized medicine and predictive intervention, with potential applications in maintaining health and managing illness. Laubenbacher *et al.* (2024) highlight the use of digital twins in oncology and cardiology for improving diagnosis and treatment accuracy. In addition, Zalake (2023) explores Digital Twins of Doctors (DTDs) to enhance health information credibility, prepare patients for visits, manage post-visit follow-ups and deliver repetitive information efficiently. However, challenges such as patient biological heterogeneity and regulatory issues regarding data privacy remain significant hurdles to overcome.

Table 1. Definitions of digital twins

Authors	Definition	Context	Discipline
Grieves and Vickers (2017)	"A set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level" [Pg 94]	Product life cycle management	Multidisciplinary
Bolton *et al.* (2018)	"A dynamic virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning" [Pg 782]	Customer Experience challenges	Service Management
American Institute of Aeronautics and Astronautics	"A set of virtual information constructs that mimics the structure, context and behavior of an individual or unique physical asset, that is dynamically updated with data from its physical twin throughout its life-cycle, and that ultimately informs decisions that realize value" [Pg 5]	Used as a theme in call for papers on Digital Twins in Nature	Aerospace
Lee *et al.* (2020)	"Digital twin integrates historical and real-time data obtained from physical systems with physics-based models and advanced analytics to create digital counterparts with high integrity, awareness, and adaptability to provide predictive services to manufacturing entities" [Pg 34]	Intelligent Manufacturing	Engineering (Smart Manufacturing)
Jones *et al.* (2020)	"A digital twin is a digital representation of an active unique product (real device, object, machine, service, or intangible asset) or unique product-service system (a system consisting of a product and a related service) that comprises its selected characteristics, properties, conditions, and behaviors by means of models, information, and data within a single or even across multiple life cycle phases" [Pg 50]	Manufacturing	Production Engineering
Liu *et al.* (2021)	"Digital twin is a digital entity that reflects physical entity's behavior rule and keeps updating through the whole lifecycle" [Pg 351]	Digital twin research perspective of concepts, key technologies, industrial applications	Manufacturing Systems and Industrial Engineering
Van Der Horn and Mahadevan (2021)	"A virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems" [Pg 2]	Complex Systems	Information Systems and Data Analytics
Ukko *et al.* (2022)	"A digital twin is defined as a digital replica of a physical entity, namely, a product, process or system" [Pg 254; 255]	Digital Twins for Organizational control	Information Technology
Fukawa and Rindfleisch (2023)	"A digital replica of a physical entity that evolves over its life cycle" [Pg 396]	Digital Twins for Innovation	Product Innovation and Management

(*continued*)

Table 1. Continued

Authors	Definition	Context	Discipline
Kowalkowski *et al.* (2023)	"Digital twins are the cornerstones of the enterprise metaverse, being virtual representations of physical assets, systems or processes" [Pg 292]	B2B Service	Service Innovation
Huang *et al.* (2024)	"A digital twin is a virtual representation of a physical entity (such as a part, product, process, or system) that is constantly updated using real-time data to generate dynamic insights and inform decisions which can then be fed back to the real world." [Pg 3]	Digital Twins in the Food Supply Chain	Logistics and Food Supply Chain Management
Katsoulakis *et al.* (2024)	"A virtual representation of a person which allows dynamic simulation of potential treatment strategy, monitoring and prediction of health trajectory, and early intervention and prevention, based on multi-scale modeling of multi-modal data such as clinical, genetic, molecular, environmental, and social factors etc" [Pg 2]	Digital Twins in Healthcare	Digital Medicine
Current study	"A CX digital twin is a virtual model of a service system or process that reflects real-time operations, enabling businesses to monitor, simulate, and predict outcomes, facilitating proactive adjustments to improve the experience"	CX Digital Twins	Services

Source(s): Authors' own work

Regarding food, the utility of digital twins is noted by Shrivastava *et al.* (2022), who developed a digital twin for citrus fruits to enhance quality and marketability throughout the supply chain. They demonstrate through the analysis of commercial citrus shipments the potential of digital twins to provide real-time monitoring and actionable insights for improving food quality. Meanwhile, a systematic review of 81 articles undertaken by Huang *et al.* (2024) identified digital twins as a key trend in Food Supply Chains (FSCs) for monitoring, simulation and scenario analysis. Their research proposes a new framework for implementing digital twins in FSCs, offering practical guidance and directions for future research in the food industry.

In sum, the majority of the digital twins literature focuses primarily on technical approaches, methods of analysis and the associated challenges of integration and data collection, as well as practical implementations of digital twins within manufacturing, health, agriculture and engineering. While Bolton *et al.* (2018), Kowalkowski *et al.* (2023) and Toubia *et al.* (2025) have briefly defined and touched on the benefits of this technology, the exploration of implementation strategies of digital twins in service research is still in its infancy.

3. CX digital twins conceptual framework

Our article introduces a conceptual framework demonstrating how organizations can leverage digital twins technology in CX within service contexts following the conceptual development process proposed by Kozlenkova *et al.* (2024). This framework, shown in Figure 1, presents a four-dimensional CX digital twin that incorporates assets, digital replicas (agents), data exchange and feedback loops throughout the customer journey. By adopting PA theory, we point out that the asset consists of physical, process, technology systems, and social elements, while data exchange includes historical, real-time and synthetic data. The AI agents, acting as the digital replica, support modeling, predictions, simulations, visualization, intervention actions, reconfiguration and innovations, all operating within a feedback loop.

In service contexts, physical and virtual processes alternate in collaboration throughout the customer journey. The digital twin enables extensive data exchange and real-time interactions, with the digital replica instructing AI agents to analyze existing and real-time data and, in some instances, generating synthetic data for simulation purposes. This allows organizations to anticipate problems through insights gained, intervene before negative events occur, identify opportunities to delight customers, co-design innovative offerings using existing and simulated data, and equip frontline employees with the tools to enhance the CX. The next section outlines the four dimensions of the CX digital twin.

3.1 Asset

An asset is a physical, tangible entity that exists in the real world, ranging from equipment to infrastructure systems (Saracco, 2019), which could include even the human body. Many aspects of physical assets have a pervasive impact on CX, influencing the nature and quality of interactions between employees, customers and the assets (Bitner, 1992). Asset information can be used to understand its condition and performance (Zaki and Neely, 2014) and enhance product and service design and configuration by providing in-context data throughout the design, operation, delivery and reuse stages (Lim *et al.*, 2020).

The predicted behavior of physical assets is continuously updated with sensor data to reflect the asset's current state (Kenett and Bortman, 2022). Digital twins can represent products, processes or entire production technological systems (Sjarov *et al.*, 2020). While explicit definitions vary, digital twins are generally characterized as virtual representations

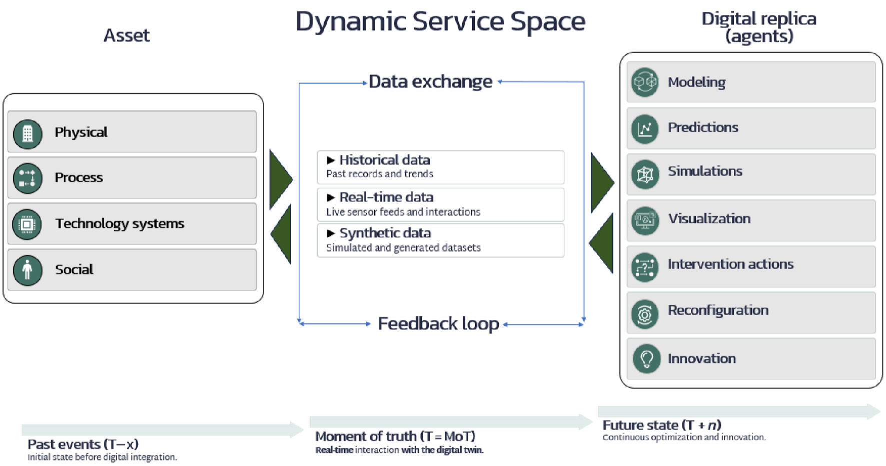

Figure 1. CX digital twins conceptual framework. Source: Authors' own work

that are coupled with physical assets (Sjarov *et al.*, 2020). They differ from conventional simulations by integrating real-time sensor data and historical information, making them valuable tools for fault classification and operational analysis in many industrial and service sectors (Kenett and Bortman, 2022). The asset is continuously monitored, and its data is captured to be replicated and understood in a digital environment (Parn *et al.*, 2024). We identify four types of assets conceptualized as follows:

3.1.1 Physical. Digital twins are digital representations of physical objects or assets, such as machines, buildings, vehicles, biological organisms or geographical regions, and they can also include components within these assets, like an engine in a motor vehicle or an endocrine system in an organism. They are connected to real objects and provide dynamic, real-time insights beyond static designs like CAD models (Sjarov *et al.*, 2020; Attaran and Celik, 2023). Digital twins are widely used to represent physical assets in industries such as manufacturing, construction, automotive, and aerospace to optimize product design, operations and maintenance schedules, enhancing overall CX. For example, in B2B construction and real estate, digital twins serve as virtual replicas of physical assets, improving asset and project management. Unlike digital technology such as Building Information Modeling (BIM), which offers static data about a building, digital twins provide real-time insights about physical assets through sensors, enabling businesses and customers to monitor and manage projects in real time (Tang *et al.*, 2019). This allows for early issue detection, resource optimization and ensures timely, cost-effective outcomes, enhancing transparency offer comprehensive asset performance data, aiding managers in making informed decisions for better CX (De-Graft *et al.*, 2021).

3.1.2 Process. At a macro level, magnifying service systems (IBM, 2024) reveal how various components work together to create an end-to-end seamless CX. Are these processes synchronized to operate at maximum efficiency, or do delays in one process impact the performance of others? Process twins can help identify issues between different processes, which ultimately affect overall functionality and experience (Tang *et al.*, 2019). A digital twin serves as a replica that represents the interaction between physical and digital processes across different processes executed within an organization or between organizations (digital thread) (Henneberg *et al.*, 2020).

In retail service contexts, a process twin can ensure that store operations, inventory management and customer service workflows are synchronized. If one process experiences delays, it can impact the CX by causing longer wait times, inventory shortages or service disruptions. By using digital twins to optimize these processes, businesses can create seamless customer journeys, minimizing delays and improving the overall CX. In Ocado's case, the online grocery platform in the United Kingdom, digital twins are used to mirror entire systems, such as automated warehouses, supply chains and delivery routes, enabling the company to optimize process workflows and operations. By feeding real-world data into these digital twin simulation agents, companies can run "what-if" scenarios, uncover inefficiencies, predict issues and continuously refine processes in real time before they occur (Ocado, 2024).

3.1.3 Technology systems. System twins are digital replicas of complex systems like power plants, transportation networks, cities or the Earth, designed to integrate and analyze data from multiple sources, both internal and external. For example, in the energy and climate sector, digital twins leverage advanced technologies like Supervisory Control and Data Acquisition (SCADA) systems, IoT devices and Geographic Information Systems (GIS). SCADA systems support real-time monitoring and management of power generation, transmission and distribution by collecting data from remote devices, allowing operators to monitor performance and respond quickly to incidents. IoT devices, including sensors and smart meters, are integrated into the power system to provide real-time data on variables such as voltage, current, temperature and environmental conditions. GIS technology enhances this by capturing and analyzing spatial data related to power infrastructure, offering detailed visual representations of networks, including power plants, substations, transmission lines and distribution grids (Yassin *et al.*, 2023).

By modeling system behavior, they help organizations optimize performance, enhance operational efficiency, reduce downtime, detect disasters and improve safety. For example, NVIDIA's Earth-2 climate digital twin cloud platform simulates and visualizes global climate and weather patterns using AI technology. This digital twin enables organizations to create high-resolution climate simulations, such as typhoons and local cloud cover, with exceptional speed and detail. The platform uses generative AI models to produce synthetic data for high-resolution, efficient simulations, enhancing forecast accuracy and enabling early adopters like the Weather Company and Taiwan's Central Weather Administration to use Earth-2 to improve disaster response and weather prediction accuracy. NVIDIA's Omniverse enables users to integrate real weather data into digital twin environments, supporting enhanced analysis and planning (NVIDIA, 2024).

3.1.4 Social. Social assets encompass interactions that can involve customer behavior, employee workflows or organizational collaboration with actors in the service ecosystems. These interactions can take various forms: human-to-human (e.g. employees with customers, customers with other customers or employees with fellow employees), human-to-non-human (e.g. customers or employees interacting with digital twin services), human-to-actors (service network participants) (Bolton *et al.*, 2018) or even non-human-to-non-human (e.g. AI agents collaborating with each other).

Digital twins have the potential to significantly impact CX by providing interactive, real-time simulations that allow both customers and frontline employees to engage with digital replicas of products, services and environments. By incorporating digital twins, organizations can empower employees to optimize the service environment in real time (Lim *et al.*, 2020), promoting the co-creation of personalized experiences (Blumel *et al.*, 2024).

Frontline employees play a vital role in this process, as they facilitate interactions that meet customers' utilitarian, social, and psychological needs. Whether in physical or digital environments, frontline employees can work alongside digital twins and other interactive technologies to connect with customers (Benoit *et al.*, 2017). These technologies enhance the collective sense of social presence – not only between customers but also among customers, employees and even non-human entities such as AI agents (Bolton *et al.*, 2018).

Analyzing customer or workplace interactions can benefit from digital twins, which provide actionable insights for improvement. For instance, GEA, a global leader in technology systems, faced challenges reopening its cafeteria at the Oelde site post-COVID-19 lockdown while ensuring employee safety and compliance with government guidelines. Partnering with Dassault Systèmes, GEA used Computational Fluid Dynamics (CFD) to create a digital twin of the cafeteria, simulating airflow and virus droplet dispersion. This revealed hotspots for virus concentration and high-risk surfaces like trays and tables. Based on these insights, GEA reconfigured seating, enhanced ventilation and communicated safety protocols effectively. This data-driven approach not only minimized health risks but also improved employee confidence and experience, ensuring a safe and positive dining environment (GEA, 2020).

3.2 Data exchange

The effectiveness of a digital twin depends on the continuous flow of data between the physical asset and its digital replica. Data exchange is the lifeblood of the twin and enables its core functionalities. Establishing relationships and achieving synchronization between the digital replica and physical assets involves sensing changes in the environment, machines, people and other elements within a service environment (Kenett and Bortman, 2022). This process primarily includes data access, description and transformation from sensors, intelligent terminals and other devices, where the IoT plays a crucial role (Gaiardelli *et al.*, 2021).

Digital twins use real-time data from sensors embedded in physical entities to provide insights into their behavior, performance and condition (Parn *et al.*, 2024). For example, manufacturing sensors monitoring temperature, pressure and vibration enable the detection of maintenance needs and optimization of services (Zaki and Neely, 2014). The types of data exchanged include historical data, real-time data and synthetic data.

3.2.1 Historical data. It includes past records about the asset's performance, such as previous maintenance logs and operational history. This can include previous customer relationship management (CRM) data, customer service interactions, call center ticketing data and long-term customer behavior patterns. Such data is vital for making accurate predictions and simulating future behaviors (Zaki, 2019). By analyzing this historical information, a digital twin can identify trends, recurring frictions and anomalies that have occurred over time, providing deeper insights and context for decision-making and future optimizations in CX management (Holmlund *et al.*, 2020).

3.2.2 Real-time data. This is live data that is collected through sensors and monitoring tools installed on the asset or in its environment. Real-time data could include the current operational status, sensor readings, temperature, vibration, speed or pressure, depending on the asset type. For example, a physical store might generate real-time data on foot traffic, energy usage or environmental conditions (Grewal *et al.*, 2023). A key feature of digital twin technology is its ability to synchronize with the physical entity in real time. This synchronization ensures that the digital twin reflects the latest state and condition of the physical object or system, allowing for accurate analysis and prediction. Real-time data integration and communication protocols enable seamless synchronization between the digital twin and its physical counterpart. For example, in smart grid applications, digital twins of power distribution networks are synchronized with real-time data from sensors and smart meters to optimize energy distribution and minimize energy downtime (Lim *et al.*, 2020).

3.2.3 Synthetic data. Synthetic data is artificially generated information that can be used in simulations or for predictive analysis. It can be particularly useful when real-world scenarios are difficult to replicate or involve risks. For instance, synthetic data could simulate customer behavior during peak shopping seasons or under extreme conditions, like major product recalls or sudden changes in market demand. This allows the digital twin to model customer responses and test various strategies, such as customer service interventions or promotional campaigns, without the risk of real-world consequences. By using synthetic data, businesses can explore and predict outcomes beyond what is available from existing customer data.

3.3 Digital replica (agents)

The digital replica of the physical asset mirrors its characteristics. This twin continuously evolves by collecting and processing real-world data. This representation encompasses geometric, functional and behavioral characteristics that mimic those of the physical object or system. Advanced modeling and simulation techniques are used to create a high-fidelity digital twin that accurately reflects the real-world counterpart. For instance, in automotive design, digital twins of vehicles are used to simulate crash tests and aerodynamic performance. Advanced modeling, prediction and simulation techniques are used to create a digital version that not only predicts behaviors but also adapts to suggest necessary actions or interventions to enhance the physical asset's performance (Lim *et al.*, 2020). These actions may include adjusting operational parameters and activities in the CX journey or implementing preventive measures to avoid service failures. In addition, the data and insights obtained from the digital twin are essential for service innovation. By analyzing the asset's performance under different conditions, new ideas and solutions can be developed. The digital replica contains the following key activities:

3.3.1 Modeling. This is the process of creating a mathematical or computational model of an asset, which serves as the foundation for making predictions. Modeling a physical entity, whether in the design, operational or reuse phases of an asset's lifecycle, is not a new concept. The aerospace industry has a long history of using a combination of computational and physical models to manage complex systems. As noted earlier, NASA's Apollo program utilized physical replicas and computational models during the 1960s. These tools were crucial in addressing the Apollo 13 incident (Saracco, 2019). Building on this experience, recent advancements in sensor technology and the IoT have accelerated the creation of digital models of assets (Zaki and Neely, 2014). Connectivity is now facilitated by telemetry tracking and control (TT&C) systems and sensors that provide real-time data on an asset's health, operations, location, positioning and configuration. These digital models, without the need for physical assets, demonstrate their growing role in mission planning and operations across industries, particularly in space missions (Boyes and Watson, 2022).

By embedding modeling into the CX, companies can model outcomes such as how customers will respond to a new service or product. For instance, digital twins could predict how customers might engage with a newly launched service, allowing businesses to adjust features before rollout. Moreover, models support predictive maintenance, alerting service providers to potential failures in advance, thus improving service reliability and overall customer satisfaction (Zaki and Neely, 2014). Ultimately, modeling empowers organizations to tailor the entire CX – from the initial touchpoint to post–purchase support – ensuring that every step of the customer journey is responsive, data-driven and optimized for customer needs.

3.3.2 Predictions. The digital twin's predictive capabilities are powered by advanced analytics that use both historical and real-time data. It employs various models such as regression-based time-series models, moving averages, auto-regression models, classification models (e.g. decision trees and random forests), support vector machines, graph-based methods and neural networks (Holmlund *et al.*, 2020). These predictive tools provide organizations with insights into likely future outcomes, enabling proactive management of CX (Zaki, 2019). For example, consider Siemens's use of digital twins in manufacturing plants. Siemens employs digital twins to monitor and predict the performance of machinery on the factory floor. By analyzing data collected from sensors in real-time and comparing it with historical wear and performance patterns, the digital twin can accurately predict when specific machines are likely to require maintenance. This predictive insight allows Siemens to schedule maintenance activities proactively, preventing unplanned downtime and optimizing production efficiency (Siemens, 2024). This approach not only minimizes operational disruptions but also enhances the CX for Siemens' customers, as they offer value-added services, demonstrating how a data-driven approach can transform CX through efficient and reliable operations.

3.3.3 Simulations. Scenarios can be simulated within the digital twin environment to evaluate how an asset or process would perform under various conditions, allowing organizations to determine the optimal actions or outcomes. By leveraging techniques – such as mathematical programming models for optimization, queuing models for process efficiency, efficient frontier methods for resource allocation and discrete event simulations – organizations can quantify and test different strategies to improve performance and CX (Holmlund *et al.*, 2020). These models help provide actionable insights, such as determining the best allocation of resources for CX enhancements.

GE Healthcare leverages digital twins to optimize the performance and maintenance of medical equipment like MRI machines. These virtual models, integrating real-time sensor data and historical usage, simulate operational scenarios to predict issues and determine optimal maintenance strategies. For instance, when an MRI machine nears its maintenance threshold, the digital twin evaluates schedules based on hospital operations, patient appointments and technician availability. This minimizes downtime, reduces patient waiting times and enhances care quality, improving hospital efficiency and the overall healthcare experience (GE Healthcare, 2024).

3.3.4 Visualization. Visualization is a central capability of the digital replica within the CX Digital Twins Conceptual Framework. While traditional dashboards typically provide retrospective, static displays of key performance indicators (KPIs), digital twins enable dynamic, real-time visualizations that evolve continuously with the service system. These visual layers are not limited to snapshots of performance metrics; rather, they function as interactive, multi-dimensional representations of customer journeys, operational workflows and systemic interdependencies over time.

By integrating historical, real-time and synthetic data streams, digital twin visualizations offer service managers a live, continuously updating view of how the service ecosystem is functioning – highlighting emerging performance trends, customer behaviors and potential disruptions. Crucially, these visualizations go beyond reporting KPIs; they can depict service heatmaps, agent workload distributions or predictive customer pathway projections, all of which can reveal latent bottlenecks or experience breakdowns before they occur. This predictive visualization enables timely intervention, supporting managers in not just monitoring but actively shaping service delivery. In this way, visualization within CX digital twins acts as an advanced decision-support mechanism, enhancing the interpretability of complex, multi-source data and fostering more anticipatory, informed and adaptive service design.

3.3.5 Intervention actions. Digital twins, combined with data-enabled CX insights, significantly improve an organization's capacity to recommend and implement necessary interventions based on predictive simulations and analytics (Holmlund *et al.*, 2020). By integrating CX data from diverse digital, physical, and social touchpoints (Bolton *et al.*, 2018), organizations can obtain a holistic view of asset performance and customer interactions, enabling them to anticipate and address potential issues proactively. For example, digital twins can forecast when a specific touchpoint, such as a customer service interface or a physical piece of equipment, might experience performance problems. By identifying these risks in advance, organizations can take timely action, such as fine-tuning operational parameters, scheduling preventive maintenance or implementing corrective measures to prevent failures. This proactive approach aligns with CX actions like touchpoint monitoring and prioritization (Holmlund *et al.*, 2020), allowing organizations to make real-time, data-driven decisions that optimize the performance of both physical assets and the overall CX.

Additionally, digital twins provide a dynamic platform for simulating potential interventions and their outcomes, ensuring that the most effective solutions are selected. By continuously monitoring and analyzing data across the various touchpoints, organizations can refine their intervention strategies over time, enhancing efficiency, reducing downtime and ultimately improving CX. This integration of digital twins and CX data empowers organizations to transition from reactive to predictive and prescriptive models of asset management and customer service, aligning operational efficiency with superior CX (Hartmann *et al.*, 2016).

3.3.6 Reconfiguration. Digital twins offer the flexibility to adapt and evolve based on changes to the physical asset, processes, technology system or social interactions. This reconfiguration capability extends to CX touchpoints, where organizations can update their digital twin models to reflect modifications or upgrades in real-time. For example, consider Tesla and its over-the-air (OTA) software updates for its vehicles. Tesla leverages digital twins to maintain a virtual model of each vehicle that aligns with the physical state of the car. When new software features or improvements are available, Tesla pushes these updates remotely. The digital twin ensures that the update process is accurately mirrored, monitoring the car's systems and configuration in real-time to maintain consistency between the digital replica and the physical car. When Tesla introduces an enhancement like improved battery efficiency or new autonomous driving capabilities, the digital twin verifies that the vehicle's digital replica state matches the updated software and hardware configurations. This enables Tesla to adapt quickly to technological advancements and customer needs without requiring vehicles to be physically serviced. Tesla customers benefit from immediate software reconfiguration enhancements without disruption, resulting in a dynamic, continuously evolving customer journey. The ability to provide such updates enhances CX (Tesla, 2024) and aligns with touchpoint journey adaptation, where organizations can proactively generate concrete actions to reconfigure assets based on their current physical state (Holmlund *et al.*, 2020).

3.3.7 Innovation. Digital twin-generated insights provide a powerful foundation for driving innovation. By analyzing how assets perform under various conditions and how customers interact with touchpoints, organizations can identify new opportunities for improvement. Digital twins enable organizations to test these innovations virtually – whether optimizing supply chains, improving product or service features or enhancing service delivery – before applying them in the real world. This supports CX innovation and touchpoint journey design, allowing organizations to create new value creation elements, touchpoints, customer emotions and cognitive responses at distinct touchpoints and modify existing ones strategically (McColl-Kennedy *et al.*, 2019), leading to both incremental and radical innovations that improve customer satisfaction and business outcomes. Organizations can design digital twins to assist in modeling and redesigning customer journeys, ensuring strategic alignment across product development, sales and communications (Holmlund *et al.*, 2020). For instance, digital twins drive agricultural innovation by simulating and managing farming operations with precision. John Deere's Precision Ag Technology leverages digital twins to optimize inputs like seeds, fertilizers and chemicals, customized for each field to maximize crop yields and profitability. Additionally, these technologies provide comprehensive data on machinery usage and input costs, enhancing financial transparency and decision-making. They also contribute to sustainability by reducing fuel consumption and minimizing the excessive application of resources, resulting in more efficient and environmentally friendly farming practices (John Deere, 2024).

3.4 Feedback loop

The feedback loop is a crucial feature of the digital twin model. It ensures that insights and actions derived from the digital twin's analysis directly impact the real-world operations of the asset. This continuous exchange of feedback between the asset and its digital counterpart keeps the system adaptable, resilient and optimized over time. The iterative nature of this process allows the digital twin to continuously refine its predictions, models and simulations based on new data, resulting in more accurate and efficient management of the physical asset. Rather than treating T–x, T = MoT, and $T + n$+1 as separate stages, our framework emphasizes the continuous alignment of past, present and future data. Historical information (T–x) informs the digital replica's models; real-time inputs (T = MoT) allow the system to detect and intervene immediately; and predictive insights ($T + n$+1) anticipate and pre-empt future outcomes. The feedback loop integrates these temporal streams, ensuring that learning from past events and simulations shapes current operations and guides future innovation. Additionally, a feedback loop records and prioritizes past user decisions, enabling the reuse of knowledge for similar situations in the future.

Numerous studies have discussed how digital twin technologies add value across various stages of engineering PLM (Lim *et al.*, 2020). However, most digital twin services are still rigid and serve single-purpose functions. Therefore, a feedback loop is essential to build a digital twin-enhanced product family design and optimization system that should improve multiple PLM stages, promoting collaboration among service ecosystem actors and generating context-aware (Lim *et al.*, 2022) and customer-centric solutions. Therefore, digital twins can support product and service generation development by facilitating systematic data flow from operational products back to the design phase, improving requirements development (Arnemann *et al.*, 2023). Overall, digital twins create a feedback loop that enables continuous improvement of products and services throughout their customer journey.

3.5 Timeline

*3.5.1 (*T-x, T = *MoT,* T + n+*1).* The digital twin timeline (T-x, T = MoT, $T + n$+1) aligns with the phases of a dynamic customer journey (Lemon and Verhof, 2016), where historical data informs the present, real-time insights drive optimal actions and predictive analytics shape future strategies. Understanding and leveraging these phases enables firms to optimize asset performance, enhance resilience and innovate continuously in response to changing conditions.

3.5.2 T-x *(Past events).* This phase captures historical data and past occurrences essential for building predictive models and understanding patterns. For example, past asset failures provide valuable insights that digital twins use to predict and prevent similar issues in the future. It functions similarly to the prepurchase phase in customer journeys, where data are gathered to understand needs and behaviors.

3.5.3 T = *MoT (Moment of truth).* The moment of truth is the (present) moment where the digital twin and physical asset are closely aligned, capturing real-time data. This phase mirrors the purchase stage in the customer journey. It is the point where real-time decisions are made, actions are executed and insights are applied to optimize the asset's performance. At this moment, the digital twin actively evaluates the system's state, applies predictive models and adjusts for maximum efficiency.

3.5.4 T + n+*1 (Future states).* This phase represents future predictions and scenarios where the digital twins apply innovations and proactive measures to adapt to evolving conditions. It is akin to the post–purchase stage in the customer journey, where continuous engagement and optimization occur. The digital twin uses predictions to anticipate challenges such as equipment failures or market demands and adapt strategies to ensure future success. This future-oriented approach also enables ongoing improvements and alignment with evolving customer needs and operational requirements. Next, to illustrate the practical application of our framework, we examine three diverse case studies.

4. Implementation of our CX digital twins framework: illustrative cases

4.1 Heavy asset B2B – shipping service illustrative case

Heavy asset organizations are centered around designing, building and delivering integrated value at the usage level (Zaki and Neely, 2014). They typically engage in producing, selling and leasing assets while integrating maintenance and repair services into their offerings. In modern manufacturing environments, these organizations leverage vast amounts of data collected from sensors embedded in their assets. This data plays a critical role in monitoring asset health and diagnosing faults through condition-based monitoring services, which utilize operational and real-time sensor data, advanced analytics and business intelligence to predict and prevent equipment failures (Tao *et al.*, 2024).

4.1.1 Without a CX digital twin. Without digital twins, heavy asset organizations rely on manual processes, traditional monitoring and reactive maintenance. Asset health is monitored through periodic inspections and routine schedules, which often lead to delayed fault detection, unplanned downtime and higher operational costs. Managing fleets, such as Rolls-Royce's remote-controlled vessels, would require larger on-site crews and depend on fragmented data and slow decision-making, increasing inefficiencies and risks. The absence of predictive and real-time capabilities limits the ability to anticipate and address failures, forcing reliance on reactive maintenance that prolongs downtime and escalates costs. Decision-making lacks immediacy, and operators struggle with minimal situational awareness, increasing the risk of navigation errors and operational disruptions. Collaboration and innovation are hindered by the lack of digital tools. Problem-solving depends on slower traditional methods, and new features like fuel optimization or autonomous navigation are tested only through costly real-world trials. CX also suffers with delays, inefficiencies and reduced reliability due to reactive strategies and limited operational uptime. A non-digital approach results in inefficiency, higher risks and constrained innovation, underscoring the transformative impact of digital twin technology in achieving seamless, proactive and customer-centric operations.

4.1.2 With a CX digital twin. An example of advanced implementation in heavy asset firms can be seen in Rolls-Royce's integration of digital twin technology to manage remote-controlled and autonomous vessels globally. Their land-based control centers, operated by small crews of 7–14 people, employ interactive smart screens, voice recognition systems, holographic displays and surveillance drones to monitor and control fleets. These technologies create a real-time, comprehensive view of on-board and surrounding vessel conditions, enabling enhanced safety, operational efficiency and navigation precision (Macdonnell Group, 2024). At the core of this system is digital twin technology, which creates virtual replicas of vessels and integrates historical, real-time and synthetic data. This enables operators to monitor vessel performance, simulate scenarios and predict potential issues. The technology fosters proactive decision-making, ensuring anomalies are swiftly addressed. By seamlessly integrating physical, digital and social elements, Rolls-Royce optimizes vessel performance, reduces risks and enhances CX. This approach supports continuous innovation by enabling data-driven strategy adaptation and service improvement (Bolton *et al.*, 2018). The assets managed in this example include remote-controlled and autonomous vessels, comprising physical components like engines and propulsion systems alongside integrated technology systems such as GPS, navigation, environmental monitoring and communication tools. These components support operational processes like navigation, docking and maintenance, while the social component is represented by the control center crew who interact with the vessels to make decisions, execute commands, and facilitate collaboration.

4.1.3 Key enhancements. Ten key enhancements are noted. First, *real-time data exchange* is fundamental to the system, ensuring constant communication between vessels and the digital twin. Second, *historical data* informs predictive modeling. Third, *synthetic data* from simulations enables risk-free evaluation of scenarios like emergencies or extreme weather. Together, these data types form a feedback loop that refines models and predictions, enabling real-time adjustments to fleet operations. Fourth, *digital replicas* of vessels within the control center mirror their physical counterparts, offering advanced functionalities such as real-time analytics and visualization technologies like holograms and drones. These replicas enhance situational awareness, optimize operations and reduce crew sizes while minimizing human error. Fifth, *modeling* is foundational to the digital twin, creating detailed representations of vessels, from their physical structures to their technology and social interactions. Predictions derived from historical and real-time data allow proactive management of issues such as engine malfunctions. Simulations test scenarios like route adjustments or emergencies, helping operators prepare contingency plans and mitigate risks without exposing assets to harm. Sixth, *intervention actions* are guided by simulations and predictions, enabling real-time decisions such as re-routing vessels or performing remote diagnostics. The control center coordinates global logistics, manages port operations and schedules maintenance, maintaining seamless operations. For example, in the event of a GPS failure, the digital twin can suggest deploying drones or activating alternative navigation systems, ensuring minimal disruption. Seventh, *reconfiguration* capabilities ensure synchronization between physical vessels and their digital replicas, adapting to changes in real-time through collaborative problem-solving. For instance, when a propulsion failure occurs, operators analyze the issue using simulations and propose solutions, such as bypassing faulty sensors. This dynamic adaptation enhances operational efficiency and reduces risks. Eighth, *innovation* thrives through data analysis enabled by the digital twin, allowing Rolls-Royce to test new features like fuel optimization or autonomous navigation in a virtual environment. This proactive, data-driven approach creates new business opportunities, such as predictive maintenance and uptime-based pricing models that align with customer needs (Hartmann *et al.*, 2016; Parn *et al.*, 2024). Ninth, the *feedback loop* from digital twin insights informs the design of future vessels, integrating performance data and operational experiences to optimize configurations and technologies. This continuous refinement ensures each new vessel benefits from accumulated knowledge. Finally, the digital twin operates across the *CX timeline*. In the past phase (T-x), historical data is analyzed to build predictive models and inform pre-journey planning. In the present (T = MoT), real-time data exchange supports immediate decision-making and issue resolution. In the future ($T + n+1$), simulations and analyses optimize maintenance and operational strategies, ensuring preparedness and enhancing both efficiency and CX (Lemon and Verhof, 2016). This comprehensive system demonstrates the transformative potential of digital twins in heavy asset management.

4.2 Retail food service illustrative case

Food recalls bring about significant financial costs. Estimates from the Grocery Manufacturers Association indicate that each product recall costs US $10 million on average, with some exceeding US $100 million when accounting for both direct and indirect costs (GMA, 2012). In early August 2024, a deli meat supplier in the United States recalled approximately 5 million kilograms of deli meats, which included pre-packaged meat and poultry products. The listeria outbreak in deli meats was responsible for 59 hospitalizations across 19 states and 10 deaths (Roeloffs, 2024; FSIS, 2024). Listeriosis causes flu-like and gut symptoms, potentially leading to severe neurological issues. It poses serious risks to pregnant women, elderly and immunocompromised individuals (FSIS, 2024). To compound matters, the affected meats were supplied to about 200 manufacturers and food service establishments nationwide and used as ingredients in thousands of ready-to-eat products (FSIS, 2024). A similar recall in the United States in 2006 due to *E. coli* led to a US$350 million loss of spinach sales and significant industry-wide effects the following year (Arnade *et al.*, 2009). In this illustrative case study, we look at the potential of digital twins through the retail food service lens to address food contamination and waste.

4.2.1 Without a CX digital twin. The Smith family – Alice, Bruce and their son Charlie – are regular customers at their local grocery store. On a typical shopping day, Alice is in a hurry to get home and get dinner ready, so she buys a packaged cheese and ham salad, for dinner. In preparation for Charlie's first day of the sports carnival, Alice makes every effort to prepare him and Bruce a wholesome dinner.

After consuming the salad, Charlie falls ill with symptoms of food poisoning, leading to a stressful evening and a late-night visit to the hospital. Sitting in the emergency waiting room, Alice is filled with dismay as she contemplates the turmoil her family has been thrown into, Charlie, who has not only become severely ill, but will now miss out on this year's sports carnival, and Bruce, who is now stressed and sleep-deprived for a presentation he needs to deliver in the morning. Alice is disappointed in herself for opting for the convenience of a prepackaged salad and vows to make the extra effort to always make her own salads from now on. The grocery store, unaware of the issue, continues to sell the contaminated product, affecting more consumers and the damage continues. This scenario illustrates the severe consequences of a reactive system that fails to prevent the distribution and sale of contaminated food products.

4.2.2 With a CX digital twin. In a digital twin-enhanced scenario, the information about food product attributes, as well as information from each step as the product travels through the supply chain, is collected and integrated using digital twins. Each product, including the prepackaged salads, has a digital counterpart that tracks its status through every phase of the supply chain in real-time. If a temperature anomaly occurs during transportation to or in the retail store, the digital twin identifies the issue, ensuring contaminated products are quarantined promptly. Triggering an automatic alert to both the distribution center manager and the retail store, advising them to quarantine the affected batch.

Even if the product manages to slip through the system and ends up in Alice's trolley, on scanning the salad at checkout, the twin detects the contaminated product, provides a notification on the self-checkout screen alerting her that the product is no longer for sale, and triggers an alert to the staff in case Alice misses the notification, preventing the negative event. She is given $10 credit for the inconvenience caused, providing an opportunity to delight. They choose a different, safe product and enjoy their meal without incident.

4.2.3 Key enhancements. Eight key enhancements are highlighted. First, there is *proactive contamination control*. Potential issues such as temperature abuse are instantly detected, allowing for immediate action and intervention to prevent contaminated products from reaching the consumer. Second, *enhanced traceability* is realized as the digital twin provides detailed and real-time tracking of the product's journey, making it easier to identify issues and pinpoint the specific batches and/or the exact supply chain points in which the negative event occurred. Third, there is *immediate and proactive communication*. Alerts and updates about potential issues are sent in real-time to all stakeholders, including the retail points and even end customers, ensuring that the affected products are removed from shelves immediately. Fourth, *health protection* is realized as consumers are protected from health risks associated with contaminated food products. Fifth, *trust is maintained*. Quick and effective handling of potential issues preserves consumer trust and the brand's reputation. Sixth, there can be *further opportunities to delight*. Through the integration of consumer loyalty programs into the digital twin system, updates on provenance and recipes can be sent directly to the consumer. Seventh, there can be *sustainability benefits*. Notifications to use the product before the use-by date to help reduce food waste are also possible, as well as informing the customer about new and innovative ways to use the products. Sensors and technology upstream in the supply chain can also lead to fewer mishaps and lower rates of product disposal. Eighth, *new product development implications* can be realized through real-time granular purchase data accessed by retailers. The digital twin of the product can integrate consumption data (e.g. date of purchase, location, items bought together), allowing for better information around purchase decisions, preferences and unlocking data for product personalization.

4.2.4 Conclusion. This case study demonstrates how digital twin technology can transform the experience by improving safety, enhancing traceability and facilitating real-time communication across the supply chain. By adopting digital twins, food processors and retailers can not only prevent health risks but also boost consumer confidence and trust.

4.3 Healthcare service illustrative case

In this healthcare case study, we investigate the potential of digital twin technology by presenting two scenarios: one where a 9-year-old girl, Lily, and her family manage her Type 1 Diabetes using traditional methods, and another where they use a smartphone-based, AI-enhanced digital twin integrated with her continuous glucose monitor (CGM) and insulin pump. These scenarios illustrate how digital twins can revolutionize diabetes management, easing the burden on the family and making the experience more manageable and empowering for Lily.

4.3.1 Without a CX digital twin. Lily, a 9-year-old girl from Sydney, Australia, was recently diagnosed with Type 1 Diabetes after an emergency hospital admission. It was a big shock for the whole family. Her parents, Sarah and Ben, are learning to manage her condition but rely on traditional methods, carbohydrate counting, finger-prick blood glucose tests, insulin injections and regular in-person appointments with their medical doctor (MD), dietitian and diabetes educator at their local primary care clinic.

The family faces the following challenges. Sarah and Ben manually record Lily's food and drink intake, physical activity and blood sugar levels (BSLs), a cumbersome task that requires attention all day, every day. They must use this complicated information to make decisions about insulin doses. However, they struggle to understand trends or predict glucose changes, leading to anxiety and errors. The MD, dietitian and diabetes educator only review Lily's data during in-person visits, often leading to reactive treatment changes based on incomplete information. With no system connecting her care team to her daily BSL trends, Sarah and Ben often worry that they may miss signs of trouble, especially when Lily is away from home. Lily feels overwhelmed and frustrated by her condition, which impacts her sense of independence. She does not fully understand why she needs to monitor everything she eats or why certain foods make her feel unwell. She often feels anxious before meals, wondering if she will get it right or if she will feel sick later. These issues lead to significant emotional and practical stress for the family. The unpredictability of diabetes management causes frequent disruptions in their daily routine, and Lily struggles with feelings of isolation and frustration. The fragmented communication between home, school, and the medical clinic, combined with reactive treatment adjustments, also leaves the family feeling uncertain and overwhelmed by the complexity of Lily's diabetes management.

4.3.2 With a CX digital twin. Now imagine a scenario where Lily's diabetes is managed with the support of a CX digital twin app on her smartphone. This system is fully integrated with her CGM, insulin pump and smartwatch, and enhanced by an AI avatar named "Sunny," who helps Lily and her parents make decisions about her meals and insulin doses. No more need for finger-prick tests or complicated calculations. The digital twin transforms their experience.

Throughout the day, Lily has conversations with Sunny about what she is eating and drinking, while the digital twin receives blood sugar information from her CGM and controls the insulin doses she receives from her insulin pump. Using integration with Australian food composition databases, the app automatically calculates the carbohydrate and nutrient content of meals and analyzes her blood sugar responses in relation to the food she has eaten and the amount and type of insulin given. Her smartwatch constantly relays information to her digital twin about her activity level and other biometric information like heart rate and sleep quality. The app sends real-time alerts to Lily's parents, MD, dietitian and diabetes educator. They can remotely monitor Lily's food intake, activity and glucose trends, coordinate care planning and collaborate with Sunny to adjust her treatment plan, ensuring that her care remains personalized and up to date.

Learning from Lily's glucose trends and insulin sensitivity, the digital twin suggests food choices and portion adjustments to optimize her blood sugar control. For example, if her glucose tends to spike after certain meals, it recommends lower-GI alternatives based on Lily's taste preferences. Lily receives positive feedback from Sunny and earns points and badges for logging her meals, checking her glucose, and making healthy food choices. At home, when Sarah is preparing dinner, Sunny can interact with the whole family. "How about chicken stir fry with brown rice tonight? It's full of fiber, is a family favorite, and it'll keep Lily's blood sugar levels steady for the evening!"

4.3.3 Key enhancements. At least four key enhancements are achievable through a digital twin. First, *real-time monitoring and automated adjustments* can be realized through the digital twin's integration with the CGM and insulin pump, which reduces the need for manual intervention, offering more accurate glucose control and peace of mind for Lily, her parents, teachers and caregivers. Second, *AI-driven personalized guidance* is achieved. Over time, the digital twin learns from Lily's food intake, biometric data and BSL responses, identifying how specific foods and circumstances affect her blood sugar. This data ensures truly individualized advice and insulin adjustments. Third, there is *personalized, remote care.* The digital twin allows Lily's MD, dietitian and diabetes educator to stay closely involved in her care. They can review her data remotely and schedule virtual check-ins when necessary. If any concerning trends arise, the system can send alerts to both the healthcare team and Lily's parents. This reduces the need for frequent in-person visits while ensuring that her care is consistent and responsive. Fourth, *empowerment through gamification* can be realized. Sunny helps Lily make informed food choices in a fun and engaging way, teaching her about nutrition and her body while reducing her anxiety around meals. Lily feels a sense of accomplishment and autonomy as she earns points and achieves goals for managing her diabetes, turning a medical challenge into a rewarding game.

4.3.4 Conclusion. This scenario illustrates how the use of a digital twin, integrated with an AI avatar, CGM, insulin pump, smartwatch and primary care team, can dramatically improve the quality of life for Lily and her family. The digital twin transforms a stressful, high-maintenance medical condition into a more manageable, interactive and even fun experience. By reducing the emotional and logistical burdens on the family and school, it provides a sense of control and optimism for Lily as she navigates her diabetes with confidence.

5. Implication for theory: a richer conceptual lens for CX

PA theory (Jensen and Meckling, 1976) is particularly relevant because digital twins reduce information asymmetry and realign incentives. Whereas traditional service systems rely on human agents to interpret data and relay information, digital twins provide principals (such as customers or managers) with direct access to real-time and predictive insights. This redistributes power and accountability while lowering monitoring costs. Furthermore, by enabling ongoing interaction and co-design of services, digital twins resonate with value co-creation (McColl-Kennedy *et al.*, 2003; McColl-Kennedy *et al.*, 2019, which views value as co-created through resource integration and collaboration. The framework, therefore, bridges PA theory with contemporary service theories, offering a richer conceptual lens for CX. It examines how the framework's dimensions – feedback loop, data exchange and digital replica – address key concerns in PA theory, such as dynamic accountability, power redistribution and agency costs. We also consider the ethical and practical risks that may arise.

5.1 Dynamic accountability: transforming agent roles

Dynamic accountability, as enabled by the feedback loop dimension of the CX digital twins conceptual framework, represents a fundamental shift in agent responsibilities. Feedback loops provide real-time monitoring and continuous recalibration of service interactions, addressing the traditional PA challenge of moral hazard by holding agents accountable for aligning their actions with the principal's goals.

In traditional service models, agents are primarily reactive, addressing service failures or customer complaints only after they occur. By incorporating feedback loops, digital twin systems enable agents to take a proactive role, preemptively resolving issues before they escalate. For example, in a healthcare setting, a digital twin of a patient journey could detect early signs of procedural delays (e.g. from overlapping diagnostics or clinician bottlenecks) and automatically adjust scheduling systems while notifying both staff and patients. Similarly, in retail logistics, a digital twin could anticipate delivery disruptions due to weather or traffic patterns and reconfigure routing in real time, triggering updates across supply chain partners and to the customer.

This shift toward proactive, data-driven accountability also aligns with broader service management theories, including service blueprinting (Bitner *et al.*, 2008). Digital twins redefine the agent's role in value co-creation by embedding real-time intelligence and adaptability, while also transforming the static structures of service processes into dynamic, living blueprints. These theoretical connections are essential for understanding how digital twins fundamentally reshape CX management.

5.1.1 Power redistribution. Empowering principals through predictive insights. The data exchange dimension of the CX digital twins conceptual framework facilitates a redistribution of power in principal–agent relationships by providing principals (e.g. customers) with direct access to real-time insights. Traditionally, principals relied on agents to interpret service data and provide updates, creating an information asymmetry that limited their influence (e.g. McColl-Kennedy *et al.*, 2019). Digital twin systems address this imbalance by equipping principals with tools—such as dashboards and predictive analytics – that allow them to independently monitor and understand service processes.

For instance, in healthcare, a patient using a digital twin-enabled continuous blood glucose monitor gains immediate insights into their health trajectory, reducing their reliance on healthcare providers for routine updates. Similarly, in B2B services like shipping, clients can monitor fleet performance through real-time dashboards, leveraging both real-time and synthetic data to collaborate with agents in optimizing logistics decisions. Synthetic data enables principals to simulate potential scenarios, empowering them to co-design service outcomes that better align with their needs. This redistribution of power fosters a more collaborative and trust-based relationship between principals and agents, enhancing transparency and reducing reliance on traditional hierarchical structures.

5.2 Reduction of agency costs: streamlining oversight and compliance

The digital replica dimension of the CX digital twins conceptual framework significantly reduces agency costs by automating oversight mechanisms and eliminating inefficiencies associated with traditional compliance methods. In conventional systems, principals incurred high costs to monitor agents, often relying on resource-intensive audits, reporting and inspections. Digital twin systems streamline this process by simulating and predicting service outcomes continuously, ensuring that agents' actions align with the principal's goals.

For example, in asset-heavy industries like manufacturing, digital twins enable predictive maintenance by monitoring equipment performance in real-time. This eliminates the need for manual inspections and reduces operational costs while improving accuracy. Additionally, by automating compliance tasks, digital replicas minimize human error and optimize efficiency, further aligning agent actions with principal expectations. However, over-optimization for cost savings could inadvertently deprioritize customer satisfaction. For instance, an excessive focus on efficiency might reduce service personalization, highlighting the importance of balancing cost reduction with maintaining a positive CX.

5.3 Ethical and practical considerations: addressing risks

While digital twins address traditional PA challenges, they introduce significant ethical risks that must be carefully managed. Algorithmic bias, for example, can arise when the data used to train predictive models fails to reflect the diversity of customer demographics or preferences, leading to unfair or exclusionary outcomes. Moreover, the opacity of decision-making processes within the feedback loop can erode transparency, undermining customer trust and autonomy and creating new forms of information asymmetry.

Privacy concerns also warrant attention. Digital twins rely on vast amounts of real-time and historical data, raising questions about data ownership, consent and security. For instance, in healthcare applications, sensitive patient data integrated into digital twins must be protected against breaches and misuse, while adhering to stringent data privacy regulations such as the General Data Protection Regulation in the European Union or Health Insurance Portability and Accountability Act in the United States. Failure to safeguard such data could result in reputational damage, legal liabilities, and a loss of consumer confidence.

Societal implications extend beyond individual customers. Over-reliance on digital twins may inadvertently contribute to job displacement in roles that can be automated, such as maintenance technicians or customer service representatives. Balancing the efficiency gains of automation with the need for human involvement is crucial to maintaining ethical and socially responsible practices.

To mitigate these risks, ethical governance mechanisms should be embedded within the framework. Algorithmic audits, for example, can ensure that data and decision-making processes are unbiased and transparent. Co-design approaches, where principals actively participate in shaping digital twin functionalities, also enhance fairness and alignment with customer expectations. For instance, in retail, engaging customers to define key metrics for digital twin dashboards ensures that these systems reflect their priorities and reduce moral hazard. Additionally, the feedback loop provides an ongoing mechanism for refinement, addressing biases as they arise and ensuring that digital twin systems remain fair and effective.

6. Managerial implications

Our AAICE (**A**ssess, **A**nalyze, **I**dentify, **C**o-design, **E**valuate) roadmap depicted in Table 2 provides managers with specific actions to enhance CX. By addressing challenges, analyzing assets, identifying opportunities, customizing solutions and evaluating outcomes, organizations should be able to achieve transformative results in CX. Real-world illustrative examples from B2B shipping services, retail food service and healthcare highlight how digital twins reduce inefficiencies, enhance trust and empower customers, positioning firms for a long-term CX strategy.

Table 2. Our AAICE practical roadmap

Five steps	Key managerial questions
1. *Assess*: Evaluating current systems and challenges	(1) What specific CX pain points do customers face across touchpoints (e.g. delays, product failures, poor communication)? (2) How reactive are current systems in identifying and resolving challenges, and what risks do they pose to customers? (3) What are the financial, reputational, and emotional costs of these inefficiencies?
2. *Analyze*: Appraising system components and data capabilities	(1) Which assets (physical, process, social, technological) generate data critical to improving CX? (2) How can historical, real-time, and synthetic data be integrated to address operational inefficiencies? (3) What tools and systems are required to ensure seamless data exchange across touchpoints?
3. *Identify:* Spotting opportunities for digital twin integration	(1) Which customer journey touchpoints can benefit most from digital twin-enabled predictive insights? (2) How can digital twins create moments of delight by reducing stress and enhancing CX? (3) What operational processes should be prioritized for optimization?
4. *Co-design*: Customizing digital twins to business and CX needs	(1) How can digital twins be customized to address unique CX challenges in specific industries? (2) What additional features (e.g. gamification, loyalty, integration) can differentiate the CX offering? (3) How can customers be involved in co-creating value through engagement with digital twins?
5. *Evaluate*: Measuring outcomes and driving continuous improvement	(1) What KPIs should be used to evaluate the impact of digital twins on CX and operational performance? (2) How can feedback loops be leveraged to refine predictions and improve customer-facing outcomes? (3) How can insights from digital twins inform long-term CX strategies?

Source(s): Authors' own work

6.1 Assess: evaluating current systems and challenges

Managers should begin by systematically evaluating their operational environments to uncover inefficiencies, customer pain points and service challenges, thereby anticipating potential problems through advanced data-driven insights, such as identifying bottlenecks in service processes before they occur. For instance, customer complaints about delayed services or unresolved issues can signal deeper systemic failures. The absence of real-time monitoring exacerbates fragmented communication, limited traceability and missed opportunities to improve customer interactions. Such gaps can result in higher operational costs, reputational damage, and diminished customer loyalty. Leveraging CX digital twins can transform this reactive approach into a proactive strategy, enabling businesses to preemptively address these challenges by continuously monitoring key metrics and optimizing workflows. For instance, food recalls are typically reactive, with contamination only being identified after customer complaints are received, which erodes trust and incurs financial penalties. Similarly, in heavy asset industries, reliance on manual monitoring leads to increased downtime, escalated costs, and negative impacts on B2B client operations. In healthcare, scenarios like Lily's diabetes management exemplify the emotional and logistical burdens imposed by traditional methods, including manual tracking and fragmented care.

To address these challenges, managers should conduct a comprehensive gap analysis to benchmark current digital capabilities against industry best practices. This analysis will help identify areas for improvement and uncover opportunities for digital twin integration to transform CX and operational efficiency. Key managerial questions are: (1) What specific CX pain points do customers face across touchpoints (e.g. delays, product failures, poor communication)? (2) How reactive are current systems in identifying and resolving challenges, and what risks do they pose to customers? (3) What are the financial, reputational and emotional costs of these inefficiencies?

6.2 Analyze: appraising system components and data capabilities

Digital twin solutions require a comprehensive analysis of physical, process, technological and social assets, as well as the data they generate. Managers should evaluate how historical, real-time and synthetic data flows can be integrated to optimize operations and enhance CX. In healthcare, for instance, Lily's CGM, insulin pump and smartwatch provide physical data streams that, when synchronized, enable her caregivers to make data-driven, real-time decisions. In heavy asset operations, sensor data from vessel engines and propulsion systems play a critical role in predictive maintenance. Similarly, in food supply chains, IoT-enabled temperature monitoring ensures cold chain compliance, safeguarding product quality. Understanding the availability and accessibility of the right data sources – and their potential to be leveraged – is essential for managers to establish a solid foundation for effective digital twin implementation. Key managerial questions at this stage are**:** (1) Which assets (physical, process, social, technological) generate data critical to improving CX? (2) How can historical, real-time, and synthetic data be integrated to address operational inefficiencies? and (3) What tools and systems are required to ensure seamless data exchange across touchpoints?

6.3 Identify: spotting opportunities for digital twin integration

Once gaps and data capabilities are analyzed, managers should identify specific opportunities for digital twins to transform CX. These include enabling predictive, proactive and real-time interventions that optimize the customer journey. For heavy assets, digital twins can predict maintenance needs and reduce downtime, safeguarding operational efficiency. In the food industry, digital twins track and isolate contaminated products, preventing them from reaching customers, thereby reducing health risks and maintaining trust. Managers should prioritize digital twin applications in high-impact areas to drive measurable CX improvements. Key managerial questions are: (1) Which customer journey touchpoints can benefit most from digital twin-enabled predictive insights? (2) How can digital twins create moments of delight by reducing stress and enhancing CX? and (3) What operational processes should be prioritized for optimization?

6.4 Co-design: customizing digital twins to business and CX needs

Co-designing customized digital twin systems to organizational and customer-specific needs and goals ensures alignment with operational complexities and evolving expectations. In healthcare, Lily's digital twin includes an AI avatar, Sunny, to gamify diabetes management, turning a medical burden into a rewarding, personalized experience. Heavy asset firms like Rolls-Royce customize digital twins with features like drone-assisted inspections and predictive route planning, customized to optimize fleet operations. In the food sector, digital twins offer real-time alerts at self-checkout kiosks, enhancing safety while integrating customer loyalty programs. Customization ensures that digital twins address both operational needs and customer expectations, creating value at every touchpoint. Key managerial questions are: (1) How can digital twins be customized to address unique CX challenges in specific industries (2) What additional features (e.g. gamification, loyalty, integration) can differentiate the CX offering? (3) How can customers be involved in co-creating value through engagement with digital twins?

6.5 Evaluate: measuring outcomes and driving continuous improvement

The final step involves evaluating the effectiveness of digital twin implementation using sound CX and operational metrics and tools such as real-time dashboards or predictive alerts, refining systems based on feedback and driving continuous improvement. In heavy asset industries, metrics such as reduced downtime and increased fleet reliability highlight operational gains. In the food sector, metrics like the speed of contamination detection and reductions in recalls reflect the system's value in safeguarding health and trust. Regular evaluation ensures that digital twins remain aligned with organizational goals and customer needs, fostering sustained innovation. Key managerial questions are: (1) What KPIs should be used to evaluate the impact of digital twins on CX and operational performance? (2) How can feedback loops be leveraged to refine predictions and improve customer-facing outcomes? (3) How can insights from digital twins inform long-term CX strategies?

7. Conclusions and future research

7.1 Contributions

Digital twins represent a transformative advancement in CX management, offering the potential to shift from reactive problem-solving to proactive, predictive and customer-centric strategies. By conceptualizing digital twins within a CX framework, this article contributes to the understanding of how organizations can integrate physical assets, digital replicas, data exchange and feedback loops into a cohesive system. This approach has implications for improving service delivery, enhancing operational efficiency and fostering deeper customer engagement across a range of industries.

The practical applications explored highlight the adaptability of digital twins in addressing diverse service challenges. For instance, in healthcare, it empowers patients by personalizing care and streamlining service delivery. Applications in the food supply chain emphasize safety, traceability, and waste reduction, whereas in heavy asset management, digital twins optimize operational efficiency through predictive analytics. These examples collectively demonstrate the capability of digital twins to anticipate customer needs and deliver real-time insights to enhance CX.

This article makes three significant contributions to the CX and services literature. First, it advances the theoretical understanding of digital twins in CX management by offering a conceptual framework that extends the boundaries of traditional approaches, including CLV and NPS (Rust *et al.*, 2004; Keiningham *et al.*, 2007), service blueprinting (Bitner *et al.*, 2008) and CX (Bolton *et al.*, 2018; Lemon and Verhoef, 2016; McColl-Kennedy *et al.*, 2019), and is adaptable across service contexts. Second, it provides practical insights through a detailed five-step AAICE roadmap, which offers actionable guidance for organizations seeking to implement digital twin technologies. Third, the article identifies critical future research directions, encouraging scholars to explore new metrics, co-creation dynamics, ethical considerations and specific industry applications. These contributions collectively provide a robust foundation for both academic inquiry and practical implementation.

7.2 Future research directions

The integration of digital twins into CX management opens several avenues for future research, enabling scholars to address critical gaps and contribute to both theory and practice. These opportunities span metrics, co-creation dynamics, ethical considerations, industry-specific applications and technological integration. See Table 3.

7.2.1 Avenue 1 – building new metrics. One promising area of research lies in the development of advanced CX metrics tailored to the unique capabilities of digital twins. Existing metrics such as CLV and NPS are insufficient to capture the complexity of real-time interactions and predictive interventions facilitated by digital twins. Future studies should explore how organizations can design new metrics that assess system responsiveness,

Table 3. Future research directions

Avenues	Research questions
Avenue 1. Building new metrics	(1) Explore how organizations can design new metrics that assess system responsiveness, predictive accuracy and the long-term impact of proactive CX management (2) How might metrics be structured to evaluate the success of interventions like preventing service delays or delivering hyper-personalized customer recommendations?
Avenue 2. Dynamics of co-creation	(1) Which key factors drive successful co-creation and the impact of these interactions on customer satisfaction and loyalty? (2) How do customers perceive the value of participating in co-design processes? (3) What tools or interfaces best facilitate engagement?
Avenue 3. Ethical considerations	(1) What appropriate governance frameworks that balance innovation with ethical accountability, ensuring that digital twin technologies respect customer autonomy and avoid unintended harm, are needed? (2) Specifically, how can algorithmic audits and stakeholder engagement be institutionalized to mitigate risks and build trust?
Avenue 4. Industry-specific applications	(1) How can digital twins enhance learning experiences in online education? (2) How can digital twins streamline customer interactions in financial services? (3) Identify unique challenges and opportunities across industries, providing actionable insights for practitioners.
Avenue 5. Long-term impact of digital twins	(1) How do digital twins influence customer loyalty over time? (2) How do digital twins impact operational efficiency and innovation over time? (3) What is the role of digital twins in driving resilience and adaptability?

Source(s): Authors' own work

predictive accuracy and the long-term impact of proactive CX management. For example, how might metrics be structured to evaluate the success of interventions like preventing service delays or delivering hyper-personalized customer recommendations?

7.2.2 Avenue 2 – dynamics of co-creation. The dynamics of co-creation in digital twin-enabled environments also merit further investigation. Digital twins provide customers with unprecedented opportunities to shape their experiences by interacting with simulated environments or influencing service designs. Research is needed to understand the factors that drive successful co-creation and the impact of these interactions on customer satisfaction and loyalty. For instance, how do customers perceive the value of participating in co-design processes, and what tools or interfaces best facilitate engagement?

7.2.3 Avenue 3 – ethical considerations. Ethical considerations are another critical area for future research. As digital twins rely on vast amounts of real-time and historical data, issues such as data privacy, algorithmic bias and transparency become increasingly important. Future studies should explore governance frameworks that balance innovation with ethical accountability, ensuring that digital twin technologies respect customer autonomy and avoid unintended harm. For example, how can algorithmic audits and stakeholder engagement be institutionalized to mitigate risks and build trust?

7.2.4 Avenue 4 – industry-specific applications. While this article focuses on three service contexts, digital twins also have potential applications in emerging sectors such as education and financial services. Research could examine how digital twins enhance learning experiences in online education or streamline customer interactions in financial services. Comparative studies across industries could identify unique challenges and opportunities, providing actionable insights for practitioners.

7.2.5 Avenue 5 – long-term impact of digital twins. Finally, longitudinal studies are needed to assess the long-term impact of digital twins on CX and organizational performance. While initial implementations often focus on immediate gains, understanding their sustainability and evolution over time is critical. These studies could evaluate how digital twins influence customer loyalty, operational efficiency and innovation over multiple years, offering a deeper understanding of their role in driving resilience and adaptability.

By addressing these research directions, scholars can unlock the full potential of digital twins in CX management. These efforts will not only advance theoretical knowledge but also provide practitioners with actionable insights to harness the transformative power of digital twins, shaping a future where technology enhances both customer satisfaction and organizational success.

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