Smart Technologies in Business:

A Process and Product Perspective

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„Der größte Ruhm im Leben besteht nicht darin, niemals zu fallen, sondern jedes Mal wieder aufzustehen.“

Nelson Mandela

The completion of this dissertation marks the end of an extremely instructive and challenging phase of my life. I would like to thank everyone who contributed to this experience. In particular, I want to thank my Ph.D. advisor, Max, who has always challenged and encouraged me. I would also like to thank all my co-authors, colleagues, and friends at the FIM Research Center, the Branch Business & Information Systems Engineering of the Fraunhofer FIT, and the University of Bayreuth for making the past years unforgettable. A special thank goes to my family for supporting me in all phases of my life and to Julia for your unconditional love and always being by my side.

Copyright Statement

The following sections are partly comprised of content from the research papers included in this thesis. To improve the readability of the text, I omit the standard labeling of these citations.

Abstract

Smart technologies are reshaping how organizations design processes and develop products. Yet, despite their transformative potential, many firms struggle to translate technical capabilities into tangible business value. While digital infrastructures and smart systems have reached a high level of maturity, their effective integration into organizational structures and workflows remains elusive. As a result, smart technology initiatives often fall short of expectations, with many confined to isolated pilot projects rather than scaled, value-generating deployments. Numerous barriers – ranging from low organizational readiness to challenges in aligning technical systems with business objectives – hinder widespread adoption. Therefore, a more holistic approach is needed that bridges the gap between technological possibilities and strategic application.

This dissertation addresses this challenge by integrating technical and business perspectives on smart technologies to advance both conceptual clarity and practical implementation strategies. The dissertation comprises seven research papers that collectively advance a holistic understanding of smart technologies in business by integrating technical and managerial perspectives. The contributions span three interrelated areas. First, this thesis develops a conceptual foundation for analyzing the nature and evolution of smart technologies. While smart technologies have significantly transformed the way individuals, organizations, and systems interact, the underlying dynamics of these transformations remain insufficiently understood. This dissertation investigates how technological smartness arises from the interaction between human and technological actors and how the continuous advancement of technology alters the capabilities and affordances of smart systems. By examining the conceptual roots of smartness in information systems research, this work offers new insights into the dynamic relationship between technological progress and evolving action potentials.

Second, this dissertation contributes to the design of smart technologies by developing actionable knowledge for engineering smart features across varying levels of complexity. Although the technological capabilities of smart systems are rapidly evolving, practitioners still face difficulties in designing solutions that move beyond basic automation toward higher levels of autonomy and business value. This work addresses these challenges by

providing design-oriented insights into how smart technologies can be purposefully configured – from simple sensing and actuation mechanisms to fully autonomous agents. It further integrates both product- and process-centric perspectives to explore how smart functionalities can be embedded into organizational workflows and offerings, thereby supporting the smartification of core business activities.

Third, this dissertation examines the strategic application of smart technologies in business environments, with a focus on aligning technical innovation with organizational value creation. As firms increasingly explore smart technologies, they often encounter difficulties in translating technical affordances into concrete business benefits. This work addresses these challenges by drawing on empirical evidence from implementation projects to identify key success factors, capability-building pathways, and integration strategies. In doing so, it offers practical guidance on how smart technologies can be embedded into existing structures in a way that supports long-term value generation and organizational transformation.

The thesis concludes by pointing to limitations of the presented work as well as directions for future research. The overall purpose of this dissertation is to provide a holistic understanding of smart technologies by integrating conceptual, design-oriented, and empirical perspectives. It aims to support scholars in advancing theory and practitioners in implementing smart technologies effectively.

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I Introduction

I.1 Motivation

Smart technologies are present in a variety of contexts and manifestations, ranging from the efficient use of resources (e.g., smart vehicle charging) (Brandt et al., 2018) to more general descriptions (e.g., smart products, smart services) (T. A. Weber, 2017). These technologies are frequently associated with socio-technical advancements and are enabled by sensors, connectivity, data exchange, information processing, and reasoning capabilities (Alt et al., 2019). Among the most specific definitions, Alter (2020) describes a smart technology as one that "[produces] useful results through activities that apply automated capabilities and […] resources for processing information, interpreting information, and/or learning from information" (p. 384). Much like human smartness, technology's smartness is linked to rational decision-making and the ability to identify logical patterns. Technological smartness is commonly tied to features such as reactivity, adaptability, and autonomy (Benbya et al., 2020). Put simply, smart technologies are now able to execute actions, services, or tasks that were once exclusively performed by humans (Huber et al., 2019). At their core, smart technologies have the ability to sense, transmit, and receive data from other devices (Nicolescu et al., 2018). By gathering data - be it environmental or usage-related - and leveraging self-management capabilities, often referred to as self-X properties, they can independently adjust to changing conditions in their surroundings (Püschel et al., 2022; Raman & McClelland, 2019). As a result, novel forms of interaction emerge between smart technologies, people, and organizations.

In recent years, smart technologies have attracted substantial attention from both industry and academia due to their transformative potential (Leiting et al., 2022; Xie et al., 2020). As digitalization accelerates across sectors, smart technologies are increasingly recognized as key enablers of innovation, efficiency, and competitiveness (Kuch et al., 2024; Nižetić et al., 2019). Numerous industries - from manufacturing and logistics to healthcare and energy - have started to explore and implement smart solutions that leverage real-time data, autonomous decision-making, and adaptive behavior (Albrecht et al., 2024; Häckel et al., 2019; Wessel et al., 2025). This growing relevance is also reflected in rising investments, emerging startups, and strategic initiatives from global tech players. Companies expanded their smart technology portfolios (Leiting et al., 2022; Siemens, 2024), while governments and research institutions promote their development through dedicated funding programs and innovation hubs (Pham, 2023; U.S. Economic Development Administration, 2025). As such, smart technologies are not only reshaping technical infrastructures but also triggering profound changes in business models, organizational processes, and value creation mechanisms.

With the rise of the Internet of Things (IoT), smart technologies were initially associated with the embedding of sensors and microcontrollers into physical objects, enabling them to collect data and transmit information to humans or centralized systems (Oberländer et al., 2018). These early smart technologies – such as RFID-enabled inventory tags or networked thermostats like the first-generation Nest – were primarily reactive (Atzori et al., 2010). They could sense their environment and relay information, but decisions were still made by humans or rule-based control systems (M. Rosemann, 2014). Building on these foundational capabilities, the concept of smart technologies has significantly evolved over the past decade. Billions of devices have become interconnected, generating vast volumes of real-time data (Macaulay et al., 2015). This increase in connectivity marked the transition from passive data provision to active data integration. Smart technologies began to reflect not only the presence of embedded intelligence but also the devices' ability to interact with other entities across digital ecosystems (Beverungen et al., 2019). A second major wave of development was fueled by the integration of machine learning and cloud computing (Djenouri et al., 2020; Yigit et al., 2014). These technologies enabled systems to recognize patterns, learn from historical data, and make probabilistic predictions (Chatterjee et al., 2018). For instance, predictive maintenance in industrial settings - enabled by machine learning algorithms analyzing sensor data - allowed machinery to autonomously flag potential failures before they occurred (Jonas et al., 2024). Smart home systems like Amazon Alexa and Google Home went beyond basic command execution by adapting to user preferences over time, offering more personalized responses and services (Mtshali & Khubisa, 2019). The most recent phase in the evolution of smart technologies is characterized by the emergence of autonomous agents and multi-agent systems (Berente et al., 2021; Wu et al., 2021). These agents do not merely respond to inputs but act proactively, make context-aware decisions, and coordinate with other agents to achieve complex goals - often without human intervention (Baird & Maruping, 2021).

For example, in modern logistics, autonomous drones and delivery robots navigate dynamically through urban environments, adjusting their routes in real time based on traffic and weather data (Rejeb et al., 2023). In manufacturing, autonomous mobile robots (AMRs) optimize workflows by independently coordinating with production lines and inventory systems (Perez-Grau et al., 2021). Today, smart technologies encompass far more than just data collection or human-guided automation. It increasingly refers to the capacity for autonomous decision-making, self-organization, and continuous adaptation – enabled by the convergence of AI, IoT, edge computing, and agent-based systems (Chen et al., 2025; Liang et al., 2025). This shift from embedded intelligence to distributed autonomous agency represents a paradigmatic change in how smart technologies are conceptualized and utilized across sectors.

Smart technologies are combinatorial in nature (Brynjolfsson & McAfee, 2014), as they bring together a variety of emerging technologies such as the Internet of Things, cloud computing, and artificial intelligence (Sharma et al., 2023). This combination enables three fundamental capabilities: pervasive data availability, connectivity between devices, people, and organizations, and the integration of information (Adner et al., 2019; Ross et al., 2018). These foundational capabilities give rise to further digital potentials, including enhanced customer interaction and insights, personalization, customization, context-aware communication, and automation (Sharma et al., 2023). Integrating such capabilities into products and business processes is transforming organizations profoundly (Alter, 2020; Queiroz et al., 2020). Powerful yet affordable computing technologies, advanced algorithms, and vast volumes of data have made smart technologies critical assets for today's enterprises (Jorzik et al., 2024; Paukstadt & Becker, 2021). They are reshaping business operations across all areas - from forecasting, manufacturing, and service delivery to human resources and strategic planning (Sharma et al., 2023). With the continuous emergence of new tools and innovations, this technological ecosystem is rapidly evolving. Beyond their overarching impact on organizational structures and strategies, smart technologies are particularly transformative at the level of core value creation mechanisms - namely, business processes and products (Beverungen et al., 2019; Queiroz et al., 2020). It is in these domains that the capabilities of smart technologies unfold their most tangible effects, enabling not only greater efficiency and adaptability in business processes, but also fundamentally reconfiguring what products are and how they deliver value.

In business processes, smart technologies serve as powerful enablers of efficiency, agility, and responsiveness (Denner et al., 2018). By integrating real-time data streams, predictive analytics, and autonomous decision-making capabilities into core operational workflows, organizations are increasingly able to transition from reactive to proactive process management (van Dun et al., 2023). For example, in supply chain management, smart technologies allow for dynamic demand forecasting, real-time inventory monitoring, and automated replenishment decisions - reducing lead times and mitigating risk (Albrecht et al., 2024). In service delivery, AI-driven chatbots and process automation platforms streamline customer interactions, issue resolution, and back-office tasks, thereby enhancing service quality and reducing costs (Adam et al., 2021). Moreover, smart technologies support adaptive process execution, where business processes continuously evolve in response to contextual changes, customer behavior, or external events (Janiesch & Kuhlenkamp, 2019). As such, they are not merely tools for automation, but foundational drivers of new forms of process innovation and digital transformation.

Simultaneously, smart technologies are reshaping the nature of products themselves. Traditional goods are being transformed into intelligent, connected offerings that create continuous value beyond the point of sale (Huber et al., 2019). These “smart products” are embedded with sensors, connectivity modules, and AI-driven functionalities that enable them to collect, analyze, and act upon data in real time (Beverungen et al., 2019). A classic example is the smart vehicle, which continuously monitors its environment and internal systems, offers real-time navigation and driver assistance, and is capable of over-the-air software updates (Xie et al., 2020). In consumer markets, smart wearables track health metrics, learn from user patterns, and provide personalized recommendations (Chatterjee et al., 2018). Importantly, smart products often operate as part of broader digital ecosystems, exchanging data and coordinating actions with other devices and platforms (Beverungen et al., 2019). This transformation expands the functional scope of products, turning them into ongoing service experiences and opening new pathways for customer engagement, business models, and value creation (Baltuttis et al., 2022).

Despite the transformative potential of smart technologies for both processes and products, realizing this potential in practice remains a significant challenge for many organizations. While the technological capabilities are increasingly available and mature, effectively integrating them into existing structures and workflows proves to be far more complex (Sharma et al., 2023). The strategic and operational benefits contrast sharply with the realities many firms face when attempting to adopt and implement smart technologies in a value-generating way. For instance, a report by Gartner indicates that only 48% of digital initiatives achieve or surpass their intended business outcomes (Gartner, 2024). Further, recent surveys suggest that less than half of CIOs are currently open to adopting AI technologies within their organizations (Swain, 2024). Several obstacles hinder adoption, including organizational maturity, a strong technology-centric focus, fear of uncertainty, employee turnover, change management issues, and the need for reskilling or training personnel (Hughes et al., 2016). As a result, the diffusion of smart technologies remains limited. Although significant progress has been made in developing and deploying smart solutions - ranging from IoT-enabled devices to AI-powered autonomous agents - many initiatives remain confined to isolated use cases or pilot programs, with limited integration into core organizational workflows (Roe et al., 2022; World Economic Forum, 2018). Surveys among industry leaders reveal that organizations often face challenges in aligning smart technologies with existing business processes and product architectures, resulting in a gap between technical feasibility and business impact (Adner et al., 2019; Enholm et al., 2022). As a result, smart technologies frequently fall short of their transformative promise, despite substantial investments in infrastructure, software, and talent (Berg et al., 2023; McKinsey, 2024). Consequently, both researchers and practitioners are increasingly interested in identifying these barriers and exploring effective strategies and solutions to facilitate the adoption of smart technologies - particularly in relation to processes and products (Åström et al., 2022).

Recent research has explored the adoption barriers and enablers of smart technologies, highlighting issues such as organizational readiness, data integration challenges, and resistance to change (Jöhnk et al., 2021; Wamba, 2022). Other streams have focused on the technical architecture of smart systems, providing blueprints for deploying smart solutions (Chen et al., 2025; Jonas et al., 2024). However, these perspectives often remain siloed - addressing either the technical underpinnings or the business implications, but rarely both. To unleash the full potential of smart technologies, it is essential to move beyond technology-centric or isolated business perspectives. Instead, a holistic understanding is needed of how smart technologies transform businesses and how to extract business value from them.

Despite calls for more integrative research (Adner et al., 2019; Vial et al., 2023), there is still a lack of conceptual and empirical work that systematically connects the technical and business perspectives. To combine the technical and business perspective on smart technology, three research areas in particular must be addressed:

1. Conceptual clarity of smart technologies
2. Design knowledge on smart technologies
3. Strategic integration of smart technologies into businesses

The following section describes in detail how the dissertation connects to the identified research needs.

I.2 Research Objectives

Based on the identified research needs, this doctoral thesis combines technical and business perspectives and provides a holistic understanding of smart technologies in business. This dissertation aims to contribute to three distinct yet interrelated areas. Figure 1 shows the three areas around which the seven research contributions are arranged.

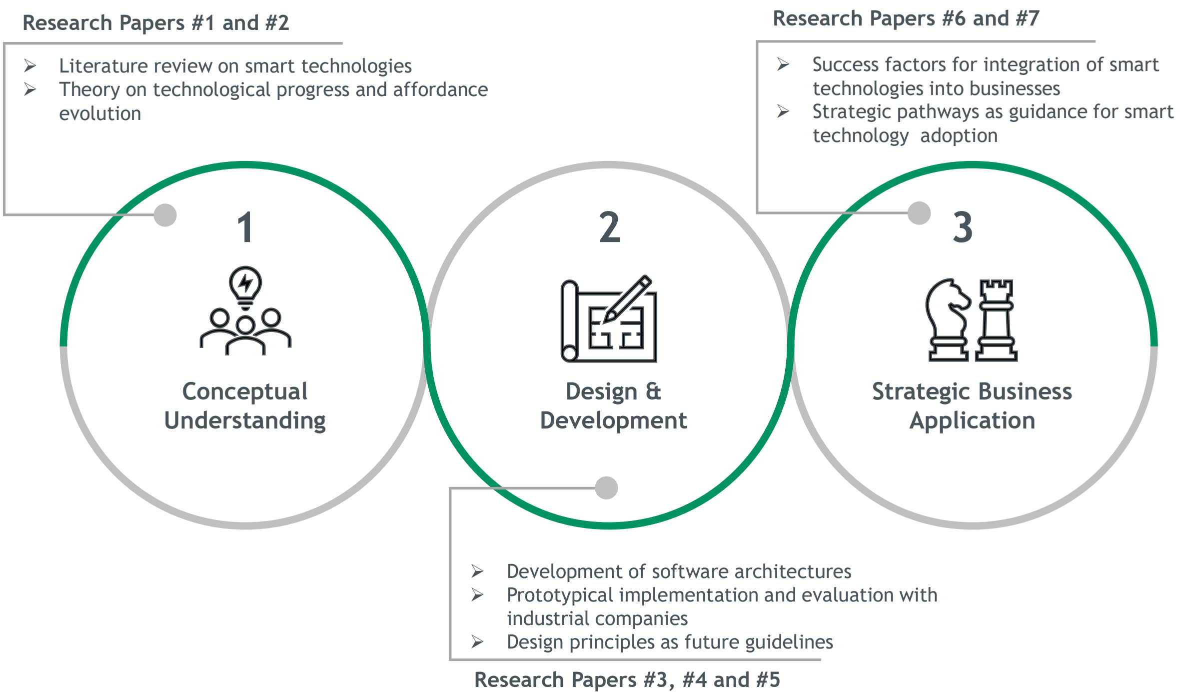


Figure 1 Overview of the Seven Research Papers for this Cumulative Doctoral Thesis

First, this dissertation lays a conceptual foundation for understanding the nature and evolution of smart technologies - serving as a basis for analyzing their design and business value. While smart technologies have transformed interactions between individuals, organizations, and systems, we still lack a theoretical grasp of how these interactions are constituted and what makes technologies "smart." In particular, this thesis aims to investigate how smartness emerges from the interplay between human and technological actors and how ongoing technological progress reshapes smart technologies' properties and action possibilities. To address the identified gaps, this dissertation analyzes the concept of smartness in information systems research and explores the interplay between technological progress and affordance evolution.

Second, this dissertation aims to advance knowledge on the design of smart technologies, contributing to the growing body of work on smartification of processes and products. While the technological capabilities of smart technologies continue to expand, practitioners still face challenges when designing technologies that go beyond basic levels of smartness and generate tangible impact. This dissertation therefore develops design knowledge for engineering smart technologies at various levels of complexity – from basic sensing and actuation to the realization of autonomous agents. Furthermore, it considers both product- and process-oriented perspectives to understand how smart technologies can be purposefully designed and operationalized in practice.

Third, this dissertation addresses the application of smart technologies in business contexts, with a particular focus on their strategic integration. As organizations increasingly experiment with smart technologies, they are confronted with the challenge of aligning technical innovation with business value creation. To support this endeavor, this dissertation provides insights into how the technical affordances of smart technologies can be leveraged to generate organizational benefits. Drawing on empirical evidence from smart technology implementation projects, the dissertation outlines success factors, capability development pathways, and integration strategies that enable companies to derive value from their deployment.

The overall purpose of this dissertation is to provide a comprehensive and holistic understanding of smart technologies - spanning conceptual clarity, design guidance, and strategic application. To this end, the dissertation integrates literature-based conceptual work, practitioner-oriented empirical studies, and design-oriented contributions to address the multifaceted nature of smart technologies. It ultimately seeks to benefit both scholars investigating smart technologies and practitioners navigating their implementation in dynamic organizational environments.

I.3 Structure of the Thesis and Embedding of the Research Papers

This cumulative dissertation comprises seven research papers that jointly contribute to the overarching objective of providing a holistic understanding of smart technologies - ranging from conceptual clarity to design guidance and strategic application. Table 1 summarizes the structure of this dissertation and the embedding of the individual research papers.

I	**Introduction**	
II	**Conceptual Foundation**	
	1	**The Concept of a Smart Action – Results from Analyzing Information Systems Literature** *Huber, R. X., Lockl, J., Röglinger, M., & Weidlich, R.*
	2	**What's Next? Toward a Theory of Technology-Affordance-Evolution** *Lockl, A., Lockl, J., Oberländer, A., & Weidlich, R.*
III	**Smartification of Processes and Products**	
	3	**Designing a Process-oriented Digital Twin for Industrial Testing Laboratories** *Weidlich, R., Albrecht, T., Derr, P. & Röglinger, M.*
	4	**Designing a wearable IoT-based Bladder Level Monitoring System for Neurogenic Bladder Patients** *Jonas, C., Lockl, J., Röglinger, M., & Weidlich, R.*
	5	**Leveraging Large Language Models for Enhanced Process Model Comprehension** *Kourani, H., Berti, A., Hennrich, J., Kratsch, W., Weidlich, R., Li, C., Arslan, A., van der Aalst, W., Schuster, D.*
IV	**Application of Smart Technologies in Business**	
	6	**Success Factors of Process Digitalization Projects - Insights from an Exploratory Study** *Baier, M.-S., Lockl, J., Röglinger, M., & Weidlich, R.*
	7	**Pathways to Developing AI Capabilities: Insights from SMEs in the Manufacturing Sector** *Meierhöfer, S., Oberländer, A., & Weidlich, R.*
V	**Conclusion**	
VI	**References**	

Table 1 Structure of this thesis and embedding of the research papers

Following the introduction and the formulation of research objectives (Section I), Section II lays the conceptual foundation for understanding the nature and evolution of smart technologies. Research Paper P1 introduces the concept of a *smart action* by synthesizing insights from the information systems literature. It provides a unifying perspective on how smartness is manifested through interactions between technological and human actors. Research Paper P2 builds on this foundation by theorizing how technological progress dynamically alters the affordances and action possibilities of smart technologies. Together, these papers offer a theoretical basis for effectively investigating the design of smart technologies and how they affect business environments.

Section III addresses the smartification of processes and products by contributing design knowledge across various domains and technological maturity levels. Research Paper P3 proposes a process-oriented digital twin architecture for industrial testing laboratories, illustrating how smart technologies can enhance transparency and responsiveness in operational workflows (process perspective). Research Paper P4 presents a design for a wearable IoT-based system in healthcare, demonstrating how smart products can improve medical monitoring through adaptive and patient-centered data processing (product perspective). Research Paper P5 investigates the potential of large language models (LLMs) to enhance process model comprehension, showcasing the intersection of advanced AI and business process design (process perspective). These three papers collectively offer guidance on how to develop and embed smart technologies in both product and process contexts.

Section IV shifts focus to the application of smart technologies in business, particularly their strategic and organizational integration. Research Paper P6 identifies critical success factors for process digitalization projects based on an exploratory interview study. It highlights enablers and barriers that organizations face when implementing smart solutions. Research Paper P7 explores capability development pathways for smart technologies based on a multiple case study in manufacturing SMEs. It reveals how firms can strategically build and scale AI initiatives to create long-term value. Both papers contribute practical insights into how smart technologies can be effectively leveraged in organizational settings.

Section V concludes the dissertation by summarizing the key findings, outlining the contributions to research and practice, and offering directions for future work. Section VI provides bibliographic references. Section VII includes an index of the research papers along with author contributions and the complete version of each research paper.

Together, the seven papers span theoretical, design-oriented, and empirical-practical perspectives on smart technologies. They address the stated research objectives in a complementary manner, offering an integrated understanding of how smart technologies can be conceptualized, designed, and applied to create business value.

II Conceptual Foundation

As motivated above, a nuanced understanding of smart technologies requires conceptual clarity on how smartness is constituted and how technological evolution shapes the possibilities for action over time. Therefore, this dissertation provides research that elucidates the conceptual foundations of smartness by introducing the notion of smart actions as the underlying mechanism of perceived technological intelligence (Section II.1; Research Paper P1) and by theorizing how affordances evolve alongside technological progress across multiple technology iterations (Section II.2; Research Paper P2). Together, the two research papers presented in this section contribute to a deeper theoretical grounding of smart technologies by addressing both the micro-level constitution of smartness and the macro-level dynamics of technology-affordance evolution.

II.1 The Concept of a Smart Action

In recent years, the notion of *smartness* has gained significant traction in Information Systems (IS) research, particularly in the context of IoT-driven innovations such as smart products, services, and systems (Porter & Heppelmann, 2015; Wiener et al., 2020). Despite this growing attention, the term remains ambiguously defined, with existing interpretations spanning from technical features and automated capabilities to socio-technical interactions and cognitive agency (Alter, 2020; Paukstadt & Becker, 2021; T. A. Weber, 2017). The conceptual fragmentation of smartness across domains and application contexts impedes both theoretical advancement and practical implementation. Current IS literature provides little clarity on how smartness is formed, manifested, and experienced, and often lacks a holistic understanding of the actors involved in smart interactions. This limits the ability of researchers and practitioners to design meaningful and effective smart systems. Against this background, Research Paper P1 investigates the following research question: *How is smartness manifested in IS research?*

To address the research question, Research Paper P1 conducts a structured literature review to conceptualize smartness in IS research. Following the approach by Wolfswinkel et al. (2013), the study applies Grounded Theory (GT) techniques to inductively analyze recurring smartness-related concepts in the IS domain. The choice of GT is motivated by the absence of established theories explaining the emergence and nature of smartness in IS. GT enables the development of theory directly grounded in empirical data and is particularly suited for exploring interaction processes, such as those between smart things and users. Through iterative coding and conceptual analysis (Gioia et al., 2013), the study identifies key components and actor roles—both active and passive—that shape manifestations of smartness. The resulting framework synthesizes fragmented insights into a coherent understanding of smartness and contributes to IS research by offering a structured, evidence-based perspective on how smartness unfolds in digital contexts.

To conceptualize how smartness is manifested in IS research, Research Paper P1 develops a theoretical model grounded in an extensive literature analysis. The study identifies recurring themes and constructs across a corpus of smartness-related IS publications. Through a process of open and axial coding based on Gioia et al. (2013), first-order concepts were abstracted into second-order themes and finally integrated into three aggregate dimensions: *action*, *system*, and *information processing*. These dimensions frame the phenomenon of smartness as emerging from specific interactions among actors, technologies, and environments. Figure 2 gives an overview of the research method. Figure 3 summarizes the result of the study.

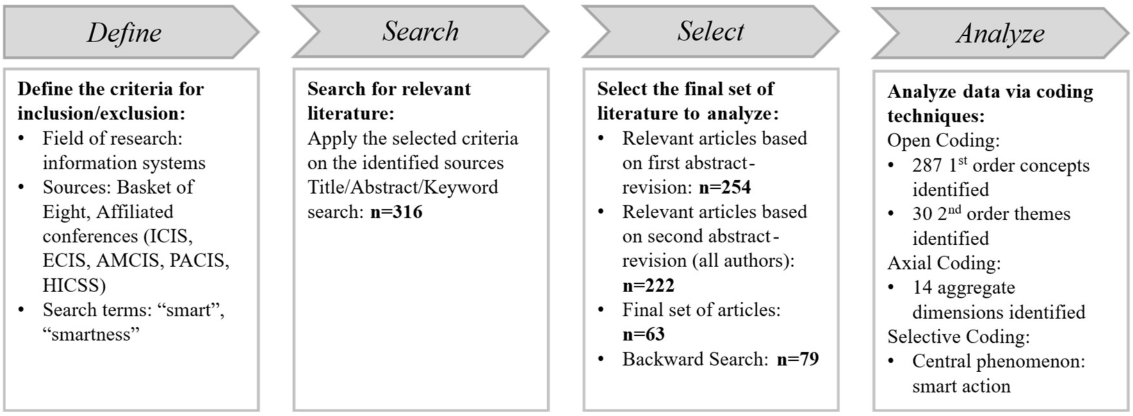


Figure 2 GT Approach (Wolfswinkel et al., 2013)

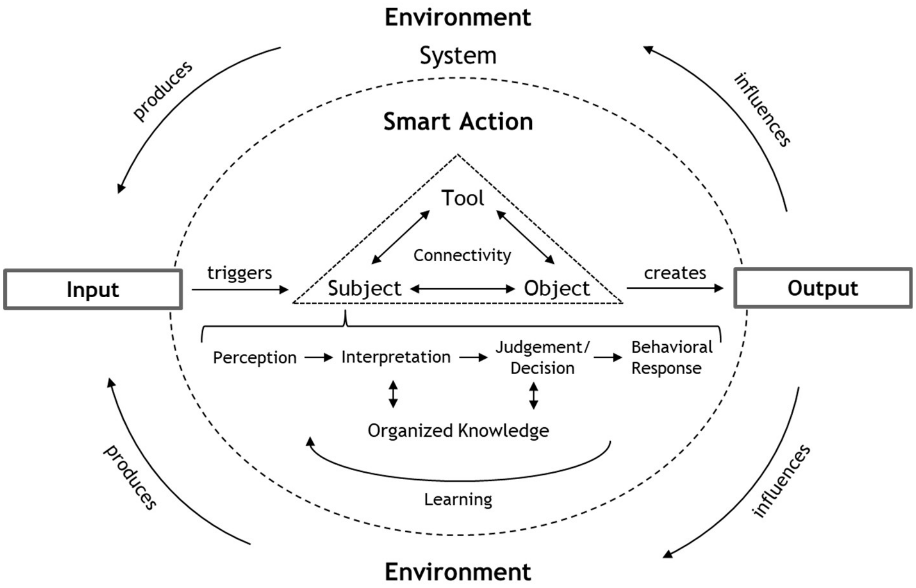


Figure 3 Graphical illustration of the concept of a smart action

The dimension of *action* captures the interaction patterns involving smart things, individuals, and physical objects. To structure these interactions, the model incorporates the concepts of *subject*, *object*, *tool*, and *connectivity*. Subjects can be individuals or smart things initiating actions. Objects can be passive recipients of those actions - be they physical objects, humans, or other smart things. Tools are intermediaries (e.g., smartphones) that facilitate the action between subject and object. The central role of *connectivity* is emphasized as it enables dynamic links between these actors and their environments. The analysis shows that smartness arises not from technology alone, but from how technologies are embedded in meaningful socio-technical interactions. Drawing on activity theory (Engeström, 1987), the paper identifies six recurring smart action patterns (see Table 2). These patterns illustrate how agency is distributed among smart and human actors and show that smart things are not only passive carriers of information but actively shape interactions. The findings demonstrate that the boundaries between actor roles - traditionally separated into subjects (humans) and tools or objects (technologies) - are increasingly blurred in smart systems. Smart things can serve simultaneously as subject, object, and tool, depending on context and interaction.

Interaction Pattern	Name, Characteristics	Interaction Pattern	Name, Characteristics

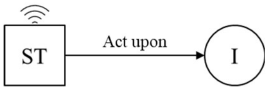
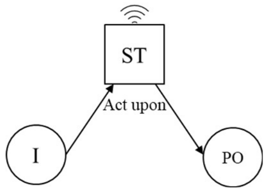
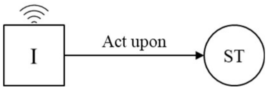
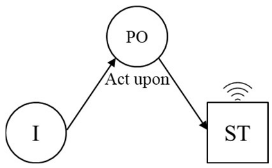
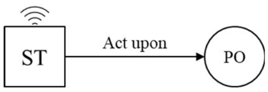
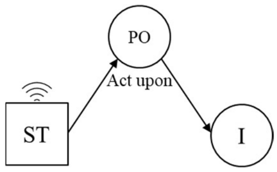
	Pattern I (ST2I) Subject: Smart Thing Object: Individual Tool: -		Pattern IV (Mediated I2PO) Subject: Individual Object: Physical Object Tool: Smart Thing
	Pattern II (I2ST) Subject: Individual Object: Smart Thing Tool: -		Pattern V (Mediated I2ST) Subject: Individual Object: Smart Thing Tool: Physical Object
	Pattern III (ST2PO) Subject: Individual Object: Physical Object Tool: Smart Thing		Pattern VI (Mediated ST2I) Subject: Smart Thing Object: Individual Tool: Physical Object
Legend:	Smart Thing = ST, Individual = I, Physical Object = PO, Interaction = ⟶		

Table 2 Smart Action Patterns

The dimension of *system* situates these interactions within broader structures. Drawing on general systems theory (Bertalanffy, 1968), the paper conceptualizes smart actions as part of systems or systems of systems. A system comprises interrelated actors and components that process *inputs* and generate *outputs*. For instance, a smart heating application and its user form a socio-technical *system*; multiple such systems can interconnect to form a *system of systems*, such as in smart cities. Smart actions are thus not isolated events but occur within - and contribute to - larger adaptive systems that exchange information and respond to changes in their *environments*.

The dimension of *information processing* addresses how inputs are transformed into outputs, a process essential to any smart behavior. Based on information processing theory, the paper outlines a five-step sequence: *perception*, *interpretation*, *decision*, *behavioral response*, and *learning*. This sequence is applicable not only to humans but also to smart things, which increasingly possess the technological capabilities to execute these steps. For example, sensors enable perception, algorithms support interpretation and decision-making, actuators perform responses, and machine learning mechanisms enable learning over time. These steps collectively turn data into action and provide the basis for smartness. *Perception* involves capturing input from the environment, using sensors (physical or digital) or human receptors. *Interpretation* structures this input and extracts meaning. *Decision* involves selecting an appropriate response based on the interpreted information, which may be simple (if/else logic) or complex (algorithmic analysis). *Behavioral response* represents the execution of the action, which can be physical (e.g., adjusting temperature) or digital (e.g., sending a notification). Finally, *learning* evaluates the outcome and adjusts future behavior accordingly. The literature distinguishes between basic learning (e.g., adapting to user preferences) and advanced learning (e.g., autonomous optimization via AI).

The study emphasizes that smartness is not binary but exists on a *continuum*—from basic to advanced levels. At the basic level, smart systems might offer suggestions based on limited user data. At more advanced levels, they autonomously adapt to complex environmental stimuli without human intervention. For example, a smart grid might forecast energy demand and automatically optimize consumption (Brandt et al., 2018). Importantly, smartness is not an inherent property of a device but emerges from its role in context-specific interactions, its ability to process information meaningfully, and its capacity to learn and adapt over time.

On this conceptual foundation, the study introduces a general definition of smartness tailored to the IS domain. It defines smartness as the *participation of things in one or more smart action patterns, where they demonstrate the ability to interact, react, anticipate, and make self-dependent decisions*. This definition captures both the technological and socio-technical dimensions of smartness and allows for contextual variation. Depending on the domain - smart homes, smart cities, smart factories - smartness may emphasize different aspects, such as personalization, public value creation, or operational efficiency (Fernando et al., 2016; Häckel et al., 2019; Marinovici et al., 2016).

This paper contributes to IS research by providing a conceptual foundation for understanding smartness through the development of a theory for analysis and description. While prior literature has extensively examined IoT applications and smart technologies, it lacks a coherent conceptualization of *smartness* itself. We address this gap by introducing the concept of the *smart action* – a structured interaction pattern in which smartness becomes manifest through the exchange of information and self-dependent behavior of smart things. Drawing from activity theory and systems theory, we identify six recurring smart action patterns, clarify the roles of actors (e.g., individuals, smart things, physical objects), and describe how these roles interact dynamically in smart socio-technical systems. Our conceptual model extends prior work (e.g., Alter (2020)) by focusing not only on technical capabilities but also on the relational and contextual emergence of smartness. We show that smartness is not inherent to devices but arises through situated interactions, supported by information processing steps such as perception, decision-making, and learning. The proposed definition of smartness is domain-independent and captures both technical autonomy and social embeddedness. This lays the foundation for future theorizing on smart technologies and supports practitioners in designing smart systems that generate value through meaningful interaction and intelligent behavior.

Overall, Research Paper P1 advances the understanding of smartness in IS by conceptualizing smart actions as the unit through which technological smartness becomes manifest in socio-technical contexts. It thereby introduces a theory for analysis and description that moves beyond technical features and sheds light on how smartness arises through interaction patterns involving individuals, technologies, and environments. This perspective lays a theoretical foundation for the dissertation's broader objective of understanding how smart technologies reshape business processes and products, not merely through embedded capabilities, but through their embeddedness in meaningful, dynamic interactions.

II.2 Technology-Affordance-Evolution

Technological progress is accelerating rapidly, making it increasingly important to understand how evolving technologies align with user goals to create value (Li et al., 2025; Steffen et al., 2019; Vassilakopoulou et al., 2023). While affordance theory has proven useful in explaining how users perceive and actualize action possibilities offered by technologies (Strong et al., 2014; Zheng & Yu, 2016), existing research predominantly adopts a static or linear perspective, focusing on single iterations of technology (Leonardi, 2011;

Thapa & Sein, 2018). The widely cited "trajectory of affordances" explains how affordances evolve within a single technology iteration through sequences of perception and actualization (Thapa & Sein, 2018). However, this perspective neglects the broader role of technological progress across multiple iterations of a technology. Therefore, Research Paper P2 argues for a shift in perspective: from analyzing affordances in isolated, single-iteration contexts to considering the spatiotemporal evolution of affordances across successive stages of technological development. We contend that affordance theory must be expanded to reflect how new affordances emerge, transform, or even re-emerge in response to technological progress over time. Ignoring these dynamics risks producing incomplete theoretical explanations and limits the guidance that affordance theory can offer to practitioners. Against this backdrop, Research Paper P2 investigates the following research question: *How does affordance evolution unfold in the course of technological progress?*

Paper P2 introduces the *Theory of Technology-Affordance-Evolution*, which explains how affordances evolve over time as a result of technological progress across multiple iterations of a technology. The theory expands on Thapa and Sein's "trajectory of affordances" by integrating the role of technological advancement as an independent driver of affordance development. The authors identify and elaborate on three distinct patterns that describe how affordances change across technology generations: (1) technology-driven affordance evolution, (2) non-consecutive technology-driven affordance evolution, and (3) affordance elimination and re-emergence. To illustrate the theory, Paper P2 examines the technological evolution of the *metaverse* as a use case.

The theory is grounded in the notion that both technologies and affordances evolve through compositional logic: new technologies are built upon existing sub-technologies (Arthur, 2009), and new affordances often extend prior ones. This recursive logic supports a co-evolutionary perspective in which changes in user goals, usage patterns, and technical capabilities collectively drive further evolution (Leonardi, 2011; Thapa & Sein, 2018). The model assumes that actors actualize affordances, which in turn generate new goals that technologies must adapt to—thus creating a feedback loop of mutual shaping between use and innovation. As a result, affordance evolution is seen not as a linear process but as cyclical and dynamic, deeply embedded in the interplay of technology, context, and agency. Figure 4 provides a graphical illustration of the theory of technology-affordance evolution.

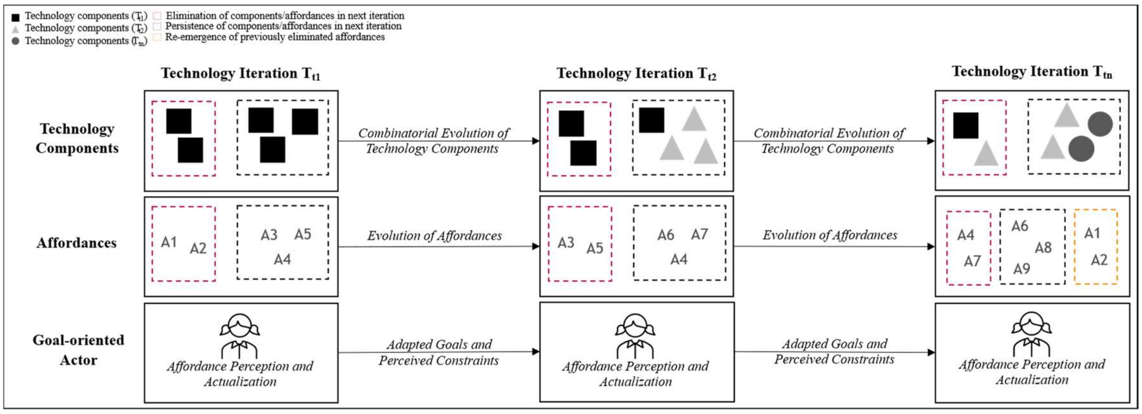


Figure 4 Overview of Technological Progress and Affordance Evolution

Pattern I (Technology-Driven Affordance Evolution) describes how a goal-oriented actor perceives and actualizes an initial affordance (A1) in a technology iteration (Tt1), leading to new user goals that cannot be fulfilled by the current technology. In response, technological progress gives rise to a subsequent iteration (Tt2), which incorporates sub-technologies of Tt1 but introduces new features that enable the emergence of a new or extended affordance (A2). This evolution is cumulative and builds upon the practical use and value of A1. A classic example is the transition from landline telephony (Tt1) offering long-distance communication (A1) to mobile phones (Tt2), which introduced the affordance of mobile reachability (A2) based on prior communication behavior and new technical capabilities. Figure 5 graphically illustrates Pattern I (i.e., technology-driven affordance evolution).

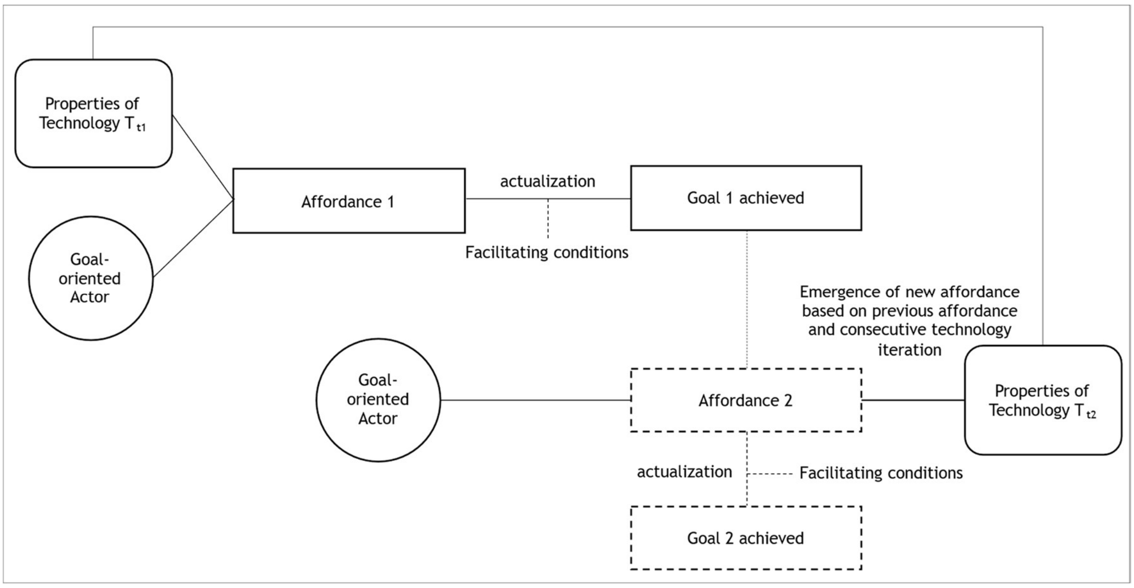


Figure 5 Technology-driven Affordance Evolution

In Pattern II (Non-Consecutive Technology-Driven Affordance Evolution), affordance evolution does not follow a consecutive timeline. Instead, an affordance A2 emerges only after a temporal gap – i.e., in a later iteration (Tt3)—while the intermediate iteration (Tt2) fails to offer a meaningful expansion of the original affordance A1. This non-linear evolution highlights that some affordances only become possible once specific technological conditions are met in later generations. For example, the affordance of audiovisual communication—made possible by smartphones (Tt3)—builds on the audio communication affordance of telephones (Tt1), while mobile phones (Tt2) did not significantly alter that original affordance. This shows that user expectations and affordance potential may "skip" a generation until technology catches up. Figure 6 graphically illustrates Pattern II (i.e., non-consecutive technology-driven affordance evolution).

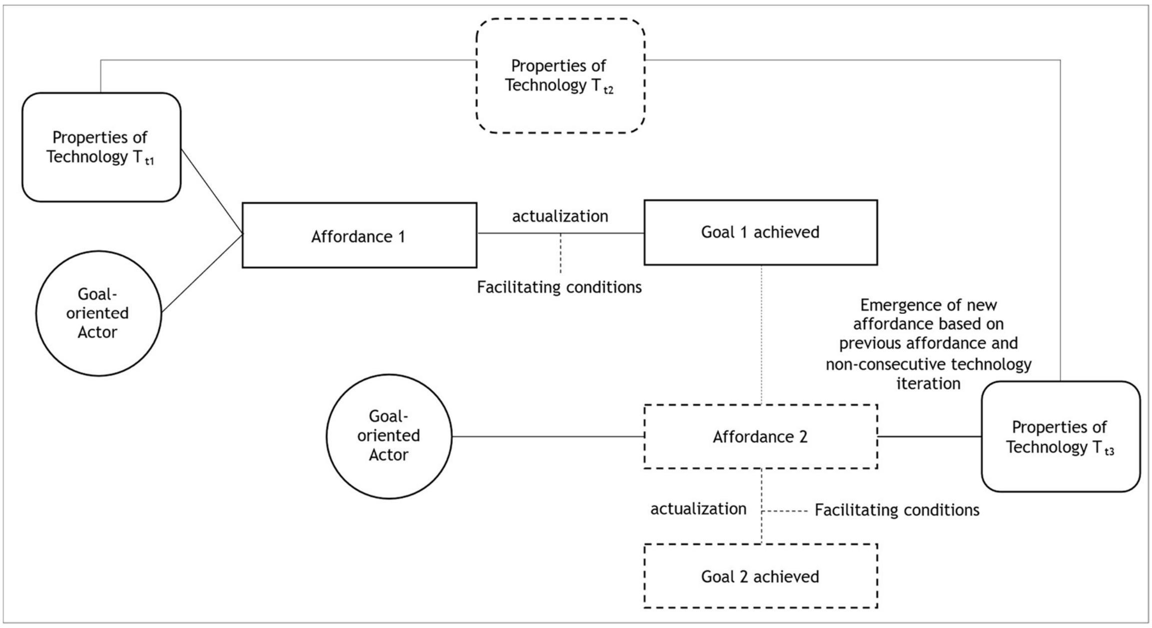


Figure 6 Non-consecutive Technology-driven Affordance Evolution

Pattern III (Affordance Elimination and Re-Emergence) illustrates how affordances may disappear due to technological or design constraints in one iteration, only to re-emerge in a different form in a future iteration. Affordances once considered essential can be temporarily lost and later reinvented when technology becomes more advanced or the context shifts. A clear example is the affordance of "office interactability" - spontaneous, informal workplace interactions - lost in the transition from physical offices to video conferencing systems. However, this affordance reappears in virtual office environments within the metaverse, reconfiguring how users experience spatial proximity and informal encounters in digital workspaces. Figure 7 graphically illustrates Pattern III (i.e., Affordance Elimination and Re-emergence).

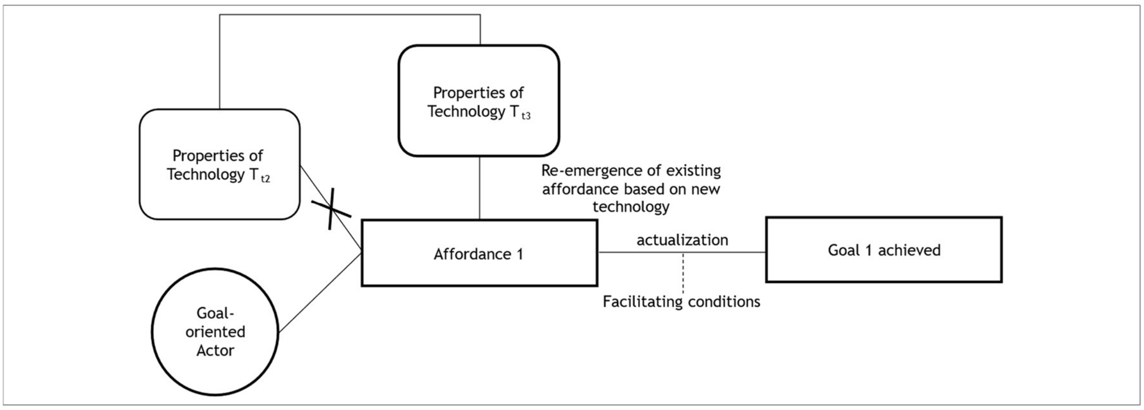


Figure 7 Affordance Elimination and Re-emergence

To demonstrate the proposed theory of technology-affordance-evolution, Research Paper P2 analyzes three real-world metaverse initiatives that reflect the conceptual patterns developed in the theory. Following a structured multi-stage selection process grounded in academic and practitioner literature, the study identifies Meta Horizon Workrooms, the OWO Suit, and ABBA Voyage as illustrative cases. These initiatives were selected based on their recent emergence, data richness, and clear relation to the metaverse concept. Using qualitative content analysis guided by Gioia et al. (2013), the study identified 11 key affordances across these cases and mapped them to the three theorized patterns of affordance evolution. For example, Meta Horizon Workrooms demonstrates both technology-driven affordance evolution (Pattern I) and affordance re-emergence (Pattern III); ABBA Voyage exemplifies non-consecutive evolution (Pattern II); and the OWO Suit illustrates both the evolution of 3D-interactability to impact sensitivity (Pattern I) and the re-emergence of physical adrenaline provocability (Pattern III). These real-world examples substantiate the theory and demonstrate how affordances evolve across multiple technology iterations in response to both user goals and technological progress.

The theory of technology-affordance evolution provides a framework for analyzing affordances from a longitudinal, cross-generational perspective. By detailing the three patterns, the model helps scholars and practitioners recognize how affordances emerge, evolve, or resurface in relation to broader technological trajectories. It not only captures the generative power of technological innovation but also calls attention to the risks of affordance loss and the implications of recontextualization. Rather than isolating affordances in static technology snapshots, this theory emphasizes that affordance meaning and availability are historically embedded and contingent on prior iterations. The three patterns support a richer theorization of how affordances can develop through incremental improvement, be delayed due to technological constraints, or be suppressed and later revived in new digital forms.

Paper P2 makes several key contributions to the understanding of affordance theory in the context of technological progress. The study addresses a gap in the literature by developing a theory of technology-affordance-evolution, extending the well-known "trajectory of affordances" by Thapa and Sein (2018). While previous research focused on the evolution of affordances within a single technology iteration, this study emphasizes a longitudinal perspective that captures affordance evolution across multiple iterations. The proposed theory introduces three distinct patterns: (1) technology-driven affordance evolution, (2) non-consecutive technology-driven affordance evolution, and (3) affordance elimination and re-emergence. Together, these patterns provide a framework to understand how affordances emerge, disappear, and reappear as technologies evolve over time. Paper P2 contributes a theory for explanation by clarifying the interplay between technological progress and affordance development. It allows researchers to analyze affordance evolution not just by actualization but also through technological innovation. Practically, the theory helps to identify affordance gaps and anticipate technological needs. It informs both research and practice by enhancing explanatory power and supporting decision-making about technology design and use, particularly in emerging domains like the metaverse.

Overall, Research Paper P2 advances affordance theory by introducing a longitudinal perspective on how affordances evolve across multiple iterations of a technology. It presents the Theory of Technology-Affordance-Evolution, which captures dynamic patterns of emergence, transformation, and re-emergence of affordances driven by technological progress. Thereby, it offers a theory for explanation that enriches our understanding of smart technologies beyond static or isolated use cases. By emphasizing the recursive interplay between user goals, technological innovation, and affordance actualization, the paper supports the dissertation’s broader objective of uncovering how smart technologies evolve over time and how their affordances can be purposefully harnessed to reshape business processes and products.

III Smartification of Processes and Products

Building on the conceptual foundation of smartness and technology evolution, this section shifts focus toward the design of smart technologies in concrete product and process contexts. While the potential of smart technologies is widely acknowledged, organizations often struggle to develop and operationalize solutions that go beyond basic automation and truly embed intelligent behavior into workflows and products. This dissertation addresses this challenge by contributing design-oriented research across diverse domains and technological maturity levels. Specifically, it presents a process-oriented architecture for digital twins that enhances transparency and adaptability in industrial testing environments (Section III.1; Research Paper P3), a wearable IoT-based healthcare system that leverages smart sensing and adaptive monitoring to improve patient care (Section III.2; Research Paper P4), and a novel approach for applying large language models to improve business process understanding through intelligent interaction (Section III.3; Research Paper P5). Collectively, these papers provide actionable design knowledge for realizing smartification in both process- and product-centric applications, thereby advancing our understanding of how smart technologies can be purposefully engineered to create business value.

III.1 Process Perspective: A Process-oriented Digital Lab Twin

Digital twins have gained increasing attention across various industries, particularly for their ability to represent physical entities through virtual models (Enders & Hoßbach, 2019). Initially applied in design and maintenance, their use has expanded to planning, monitoring, and decision-making in domains such as manufacturing, urban infrastructure, and healthcare (Hui et al., 2023; Singh et al., 2021). Despite this growing adoption, the potential of digital twins remains largely untapped in other process-intensive environments – most notably, in industrial testing laboratories (Barricelli et al., 2019; Prasad & Bodhe, 2012). Industrial testing laboratories face increasing pressure to improve efficiency while adhering to strict regulations and client demands (Belezia & Almeida, 2021; Prasad & Bodhe, 2012). These environments are characterized by high complexity, socio-technical interdependencies, and regulatory frameworks such as ISO/IEC 17025 (Grochau et al., 2020). While Laboratory Information Management Systems (LIMS) are widely used to manage lab operations, they fall short in enabling integrated, end-to-end visibility, real-time process monitoring, and predictive capabilities - features that are becoming essential for dynamic and quality-focused laboratory environments (Grochau et al., 2018). Given these challenges, digital twins offer a promising alternative. Their ability to integrate heterogeneous data sources and reflect complex process landscapes makes them well-suited to address gaps in traceability, compliance, and resource optimization within laboratories (Javaid et al., 2023). Yet, there is limited guidance on how to design such solutions for this specific context. Against this backdrop, Research Paper P3 addresses the following research question: *How should digital twins be designed to enhance business process management in industrial testing laboratories?*

Following a design science research (DSR) methodology (Peffers et al., 2007), Research Paper P3 develops a set of design principles (DPs) and a corresponding software architecture (SA) for a process-oriented digital lab twin. Figure 8 gives an overview of the conducted DSR approach. Based on challenges identified in practice and the limitations of existing laboratory information systems, Research Paper P3 derives six design principles (DPs) that guide the conceptualization of a digital twin tailored to the specific demands of highly regulated and process-intensive laboratory environments. First, Norm Conformity ensures compliance with ISO/IEC 17025 to support traceability, repeatability, and accountability (Grochau & Caten, 2012; ILAC, 2015). Second, Order Transparency enables end-to-end visibility of the lab order process for improved coordination and responsiveness (Karthiyayini & Rajendran, 2017). Third, Sample Traceability ensures real-time tracking of samples to reduce uncertainty and compliance risks (Kammergruber & Durner, 2018; Prasad & Bodhe, 2012). Fourth, Machine Integration emphasizes direct connectivity with lab instruments to automate data collection and reduce manual effort (Barthelmey et al., 2019). Fifth, Data Fusion consolidates fragmented data sources for holistic monitoring and analysis. Sixth, Process Smartness promotes automation of repetitive tasks to boost efficiency and free up expert resources (Schäfer et al., 2022).

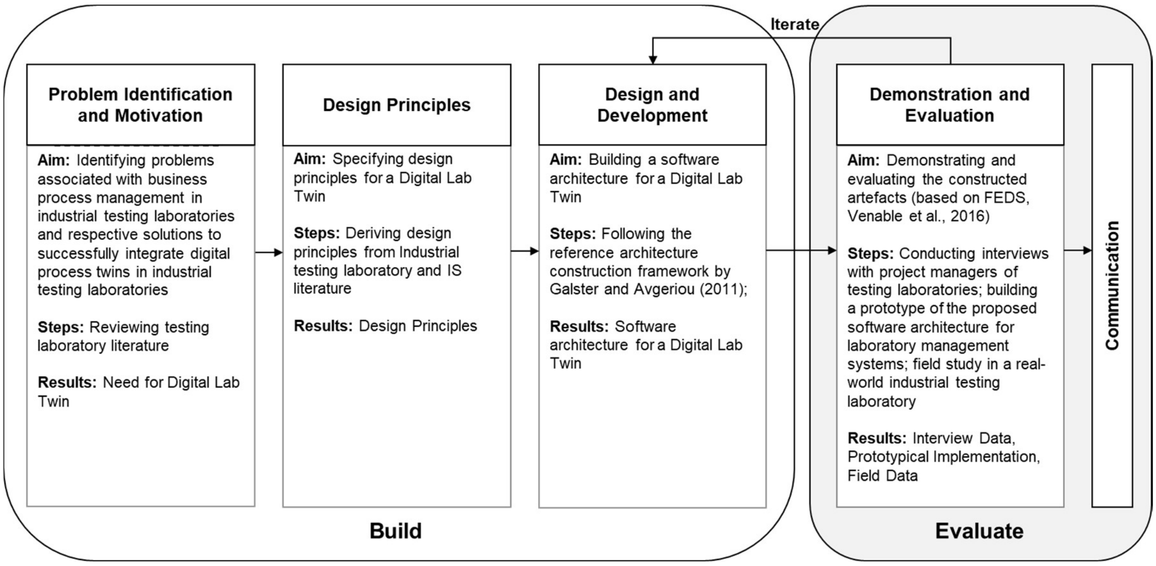


Figure 8 Our research design is based on (Peffers et al., 2007)

Based on these six principles, Research Paper P3 develops a SA that realizes the vision of a digital lab twin. The architecture is structured around two main applications: a *customer application* and a *laboratory application*. The customer application allows clients to initiate laboratory orders, specify samples, upload relevant documentation, and view test results. This component supports transparency and standardized communication between laboratories and their clients. The laboratory application supports internal operations, including order confirmation, resource planning, sample management, data collection, and result documentation. Each component of the architecture is explicitly mapped to the design principles, ensuring that the digital lab twin supports both strategic and operational process goals. Figure 9 presents the designed SA.

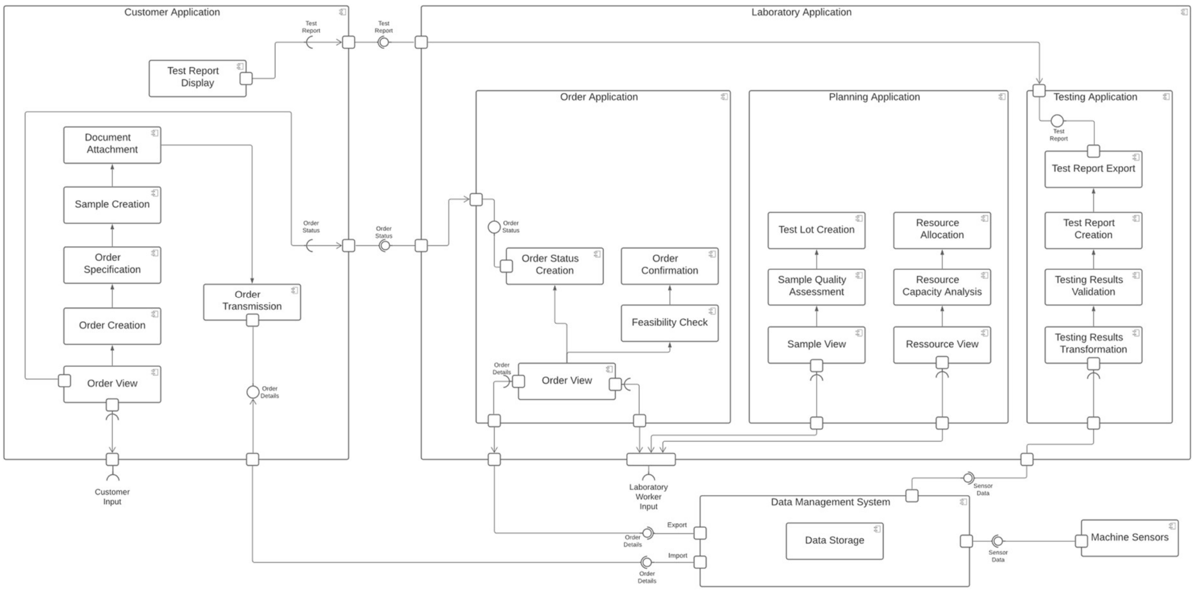


Figure 9 SA of the Digital Lab Twin

To validate the design, Research Paper P3 follows a three-phase evaluation approach aligned with the Framework for Evaluation in Design Science (FEDS) (Venable et al., 2016). Figure 10 gives an overview of the evaluation strategy. The first phase, an ex-ante evaluation, involved structured interviews with domain experts from two industrial testing laboratories. These interviews were used to gather detailed requirements, validate the relevance of the design principles, and ensure alignment with industry needs. The feedback informed the refinement of both the principles and the initial system design. The second phase involved the prototypical implementation of the digital lab twin. The prototype was designed to demonstrate the technical feasibility of the architecture and to test the interactions between system components. In this phase, emphasis was placed on core functions such as sample tracking, system integration with laboratory machines, and the visualization of order status. The prototype served as a proof-of-concept and enabled usability testing with stakeholders. In the third phase, a field study was conducted to evaluate the system's application in a real-world laboratory setting. The digital lab twin was deployed in collaboration with one of the participating laboratories and tested under operational conditions. The field study focused on order management, resource planning, and sample traceability. The results confirmed that the digital lab twin improved end-to-end visibility, reduced manual effort, and increased overall process reliability. Practitioners reported fewer inconsistencies, improved coordination between staff and departments, and higher confidence in planning decisions.

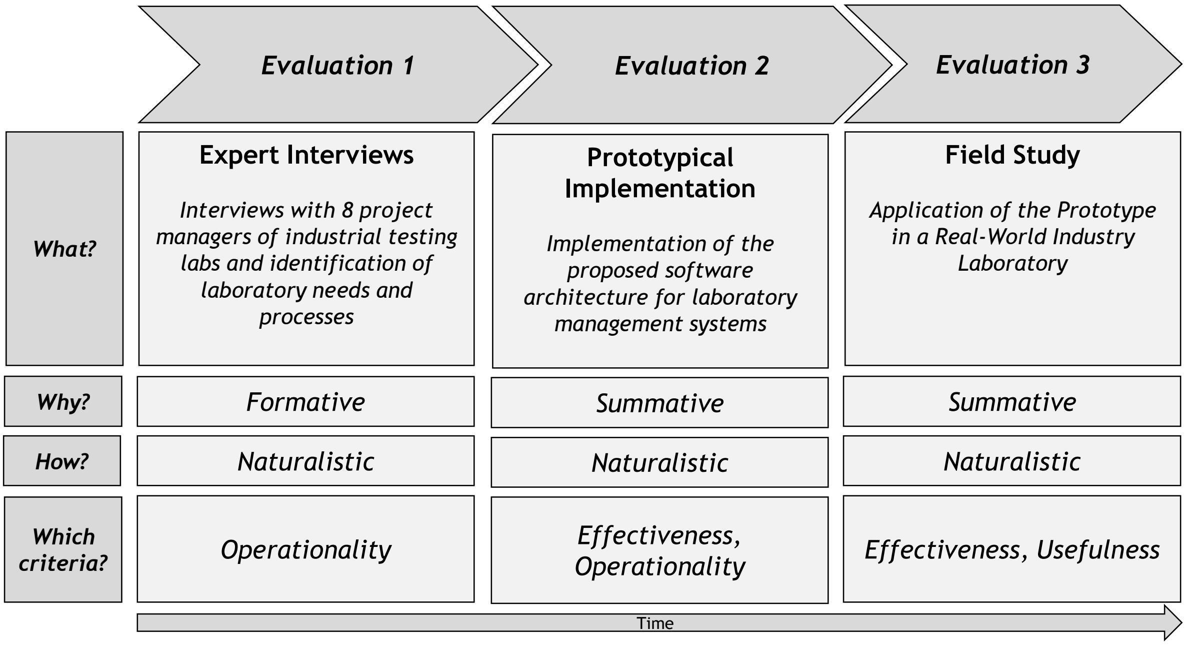


Figure 10 Evaluation strategy based on the FEDS framework (Venable et al., 2016)

Research Paper P3 contributes to the advancement of process-oriented digital twin design in regulated, knowledge-intensive environments such as industrial testing laboratories. Building on existing work in business process management and digital twin technologies, the study addresses the specific needs of laboratory operations that require traceability, standard compliance, and cross-functional coordination. The proposed digital lab twin, grounded in six design principles and implemented through a modular SA, offers an integrative alternative to conventional LIMS, which often lack end-to-end process support and adaptability. By applying digital twin concepts to laboratory settings, the study extends their scope beyond asset-centric domains and highlights how process orientation and ISO/IEC 17025 compliance can be embedded into system design. The resulting artifact serves as a Type V theory contribution, offering actionable guidance for both system development and organizational implementation. The design principles are generalizable and may inform the development of digital twins in other complex service environments, such as healthcare or telecommunications.

Overall, Research Paper P3 offers theoretical and practical insights for designing digital twins that enhance process visibility, automation, and regulatory alignment—bridging a gap between conceptual innovation and operational application. By tailoring digital twin architectures to the specific needs of regulated, process-intensive environments, the paper exemplifies how smart technologies can be purposefully designed to address domain-specific challenges. Thereby, it contributes to the overarching goal of this dissertation: to advance the smartification of processes by developing actionable design knowledge that transforms technological potential into real-world value creation.

III.2 Product Perspective: A Wearable IoT-based Bladder Level Monitoring System

In recent years, wearable health technologies have become increasingly prominent within the IS domain, particularly in the context of chronic diseases and behaviour-sensitive interventions (Bardhan et al., 2020; Brohman et al., 2020). While technological advances in the Internet of Things and wearable sensors have enabled real-time monitoring of physiological parameters, their integration into systems that support patient autonomy and behaviour change remains a central design challenge (Jiang & Cameron, 2020; Vinod et al., 2019). This is especially true for people living with neurogenic bladder dysfunctions, who suffer from a loss of sensory feedback from their bladder and must rely on intermittent catheterisation to manage their bladder (Nseyo & Santiago-Lastra, 2017). Existing solutions such as ultrasound-based monitoring are costly, impractical for everyday use, or fail to provide timely and personalized feedback (Snow-Lisy et al., 2022; Vinod et al., 2019). As a result, patients often experience either unnecessary catheterisation or delayed emptying, which can lead to social withdrawal, infections, or long-term damage (Manack et al., 2011). Afforded by recent technological developments in sensor fusion and mobile computing, wearable IoT systems offer the potential to monitor bladder filling levels non-invasively and support patients in managing their health condition proactively (Chatterjee et al., 2018; Zadeh et al., 2021). However, designing such systems goes beyond sensing capability – it requires a deep understanding of how behavioural triggers, information design, and system feedback interact with the users' experience (Fogg, 2009). Current IS research lacks prescriptive guidance on how wearable health systems can be systematically designed to influence and support patient behaviour in context-sensitive ways. Against this background, Research Paper P4 investigates the following research question:

How should wearable IoT-based systems be designed to support behaviour-sensitive bladder management for neurogenic patients?

To address this question, Research Paper P4 develops a SA and a set of five design principles for a wearable bladder level monitoring system. Grounded in Fogg's behaviour model and informed by IoT-specific design considerations, the study follows a DSR methodology (Peffers et al., 2007) and evaluates the resulting artifact through expert interviews, technical prototyping, and a real-world field study (Venable et al., 2016). The design principles provide prescriptive guidance for the development of health-oriented wearables aimed at supporting behaviour-sensitive interventions in socio-technical contexts. First, the Principle of Hybrid Trigger emphasizes that the system must incorporate both a facilitating and a spark trigger based on physiological data, enabling patients to perform precisely timed micturitions by combining ability and motivation (Fogg, 2009; Tienza et al., 2018). Second, the Principle of Non-Invasiveness requires that the system be simple and externally wearable to ensure comfort, reduce health risks, and avoid psychological burden caused by invasive methods (F. Davis et al., 2014; Prabha et al., 2021). Third, the Principle of Sensor Fusion highlights the need to combine data from multiple sensors to generate accurate, context-aware bladder level measurements that account for dynamic changes in patient posture and movement (Fong et al., 2018; Martin et al., 2021). Fourth, the Principle of Actionable Information demands that the system translate raw data into intuitive, timely, and meaningful insights to guide patient behavior and facilitate learning about their bladder activity (Baran & Yilmaz Baran, 2021; Chatterjee et al., 2018). Fifth, the Principle of Individuality stresses that data processing must be personalized and adaptive, considering individual physiological differences to ensure accurate bladder level predictions over time (Fong et al., 2018; L. Zhao et al., 2019). Figure 11 summarizes the problem setting, the derived design principles and the design specification based on the design principles.

Problem Setting	Design Principles	Design Specification
• Patients lack internal trigger to determine the moment for micturition • Patients‘ limited well-being, risk of physical damages, and psychological burden • Patients lack sensation and control over the bladder • Patients miss knowledge about the current filling level • Only bulky solutions for bladder level monitoring in stationary use • No suitable bladder level monitoring solutions for everyday use exist • Need for individualised solutions for bladder level monitoring due to uniqueness of bladder form and function	**DP1. Principle of hybrid trigger:** *BLMS should include a hybrid trigger that combines both external and internal triggers and enables patients to perform precisely timed micturition.* **DP2. Principle of non-invasiveness:** *BLMS should provide non-invasive monitoring methods in order to foster patients' well-being and avoid risking health damage.* **DP3. Principle of sensor fusion:** *BLMS should use a variety of sensors and merge the collected data to ensure accurate, precise, and contextualised measurement of the bladder level for neurogenic bladder patients.* **DP4. Principle of actionable information:** *BLMS should provide actionable information that guides patients in performing precisely timed micturition.* **DP5. Principle of individualization:** *BLMS should include individual characteristics of patients and learning to provide an accurate model of the patient for bladder level monitoring.*	• Hybrid trigger including phone notification based on measuring NIRS data in the bladder (DP1, DP4) • Measuring bladder level with non-invasive NIRS methods (DP2, DP3) • Analyzing human data using machine learning in real-time (DP3, DP5) • Combining data from NIRS, acceleration, and temperature (DP2, DP3) • Provision of precise recommendations on when to perform a micturition (DP1, DP4) • Consideration of individual patient characteristics, such as weight, height, gender, skin colour (DP5)

Figure 11 Overview of problem setting, design objectives, and design specification

Based on the five design principles, Research Paper P4 develops a SA that realizes the vision of a wearable bladder level monitoring system tailored to neurogenic bladder patients. The architecture is structured around three main components: a sensor box, a mobile application, and a server application. The sensor box collects physiological data through an infrared sensor, an acceleration sensor, and a temperature sensor, and performs initial data preprocessing to reduce transmission load. It sends processed data at fixed intervals to the mobile application via wireless communication. The mobile application receives and further processes this data, integrates patient-specific information (e.g., height, weight, skin color), and applies bladder-level detection and filtering to derive accurate status information. It also includes a full bladder trigger that notifies patients when micturition is needed and a data supervisor that initiates model retraining when inconsistencies are detected. The server application supports model training and continuous learning by hosting components for configuring, training, and exporting machine learning models. These models are updated based on patient data and re-deployed to the mobile application, ensuring personalized and adaptive monitoring. Each architectural element aligns with the underlying design principles, operationalizing the system's focus on non-invasiveness, actionable guidance, and individualized health support. Figure 12 presents the designed SA.

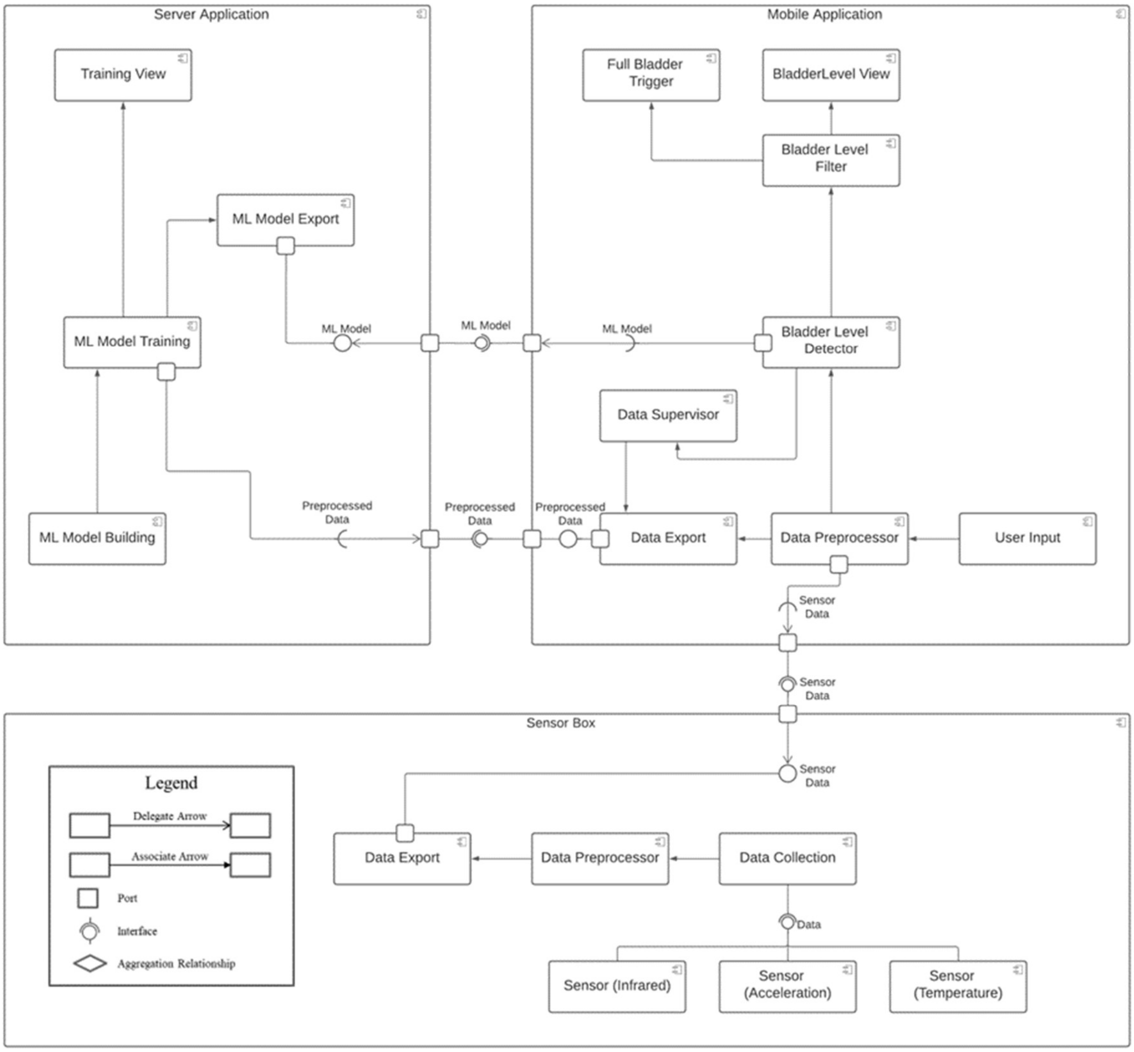


Figure 12 SA of the BLMS

To validate the artifact, Research Paper P4 follows a four-stage evaluation process in line with the Framework for Evaluation in Design Science (FEDS) (Venable et al., 2016). In the first evaluation stage, an expert workshop was conducted with experts from the healthcare technology domain. The workshop assessed the structure of the SA, whether the software components of the SA are consistent, and whether additional software components are necessary or need refinement. Feedback led to refinements in certain components of the SA (e.g., User Input component, Data Supervisor component). The second evaluation stage involved semi-structured interviews with 17 patients and 10 medical professionals. These interviews confirmed the practical relevance of the DPs and revealed key user needs such as privacy, discretion, and reliability. Respondents expressed strong interest in hybrid triggers, provided the system could predict bladder status with sufficient accuracy. The third evaluation stage focused on the technical validation of the prediction model. A prototype was implemented using the specified hardware configuration, and data was collected from 16 participants to train and test the system. The evaluation showed that the machine learning model could estimate bladder volume with a mean absolute error of 110.66 ml, which was considered acceptable by clinical standards. The hybrid trigger was successfully integrated into the app, allowing real-time notifications to be sent when the bladder approached a critical threshold. Figure 13 shows an overview of exemplary prediction results. In the fourth and final stage, a field study was conducted over several weeks with four patients using the full system in their daily lives. The study examined how the wearable bladder monitoring system influenced patient behaviour and health outcomes. Participants reported greater confidence in their bladder management, fewer unnecessary catheterisations, and reduced anxiety in social settings.

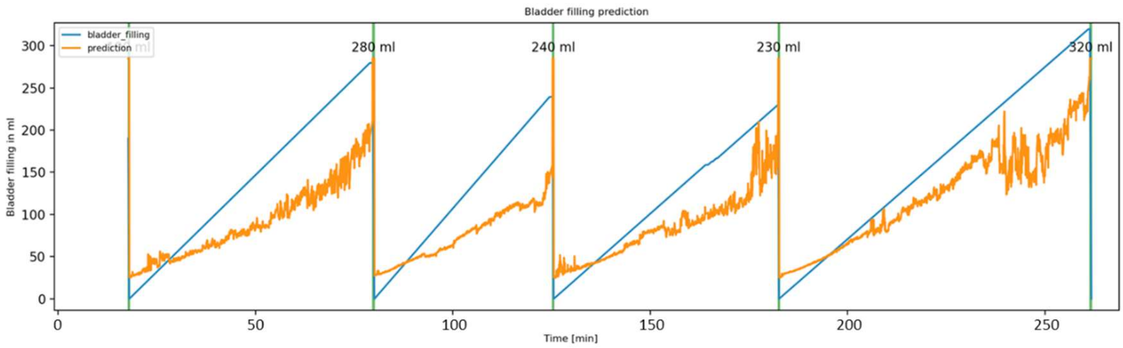


Figure 13 Exemplary prediction results

Research Paper P4 contributes to IS research by offering prescriptive design knowledge for the development of wearable IoT systems that support patient behaviour in managing chronic health conditions. While prior research has examined the technical feasibility of sensor-based systems in healthcare, this study addresses a conceptual gap by linking system design to behavioural theory and delivering actionable design guidance for real-world application. A core theoretical contribution is the introduction of the hybrid trigger concept, which extends Fogg's model by embedding physiological feedback into behavioural prompting. This enables context-sensitive interventions that simultaneously increase a user's motivation and ability to act. Furthermore, the study advances design knowledge by integrating principles such as non-invasiveness, sensor fusion, individualisation, and actionable feedback into a unified and generalizable framework. The study also contributes a Type V theory for design and action, grounded in a full-cycle DSR process including prototyping, expert validation, and field testing. The evaluation shows that the system improves user outcomes by enabling personalized, real-time, and discreet support in daily life. Beyond bladder monitoring, the design principles and architectural insights are transferable to other domains requiring behaviour-sensitive, wearable health technologies.

Overall, Research Paper P4 offers actionable design knowledge for the development of wearable IoT-based smart products that support behaviour-sensitive interventions in healthcare. The artifact illustrates how smart technologies can be purposefully designed to merge real-time sensing, machine learning, and user feedback in a patient-centric context. Beyond the healthcare domain, the study exemplifies how smart products can support autonomy and decision-making in everyday life - extending smart technologies beyond automation toward adaptive, behaviour-aware systems. Thereby, the paper contributes to the overarching goal of this dissertation: to advance the smartification of products by integrating technical sophistication with context-sensitive value creation.

III.3 Process Perspective: Large Language Models for Process Model Comprehension

Business Process Management (BPM) is a management approach aimed at aligning business processes with strategic goals (Dumas et al., 2018). It involves documentation, automation, integration, and continuous improvement to optimize performance and manage change effectively (Schmiedel et al., 2020). Process models are central to BPM, illustrating workflows, data, events, and organizational roles (Bera, 2012). They support analysis, simulation, optimization, and automation. High-quality models are crucial for operational efficiency and service quality (Vergidis et al., 2008). However, the complexity of real-world processes often leads to models that are difficult to understand and maintain. The Business Process Model and Notation (BPMN) has become the industry standard for process modeling (Rosing et al., 2015). While industry practice typically uses a limited subset of BPMN elements (zur Muehlen & Recker, 2013), the full set enables modeling of complex scenarios. This versatility enhances expressiveness but also increases model complexity and the risk of cognitive overload (Bera, 2012; Recker, 2010). Artificial Intelligence, particularly Large Language Models (LLMs) like GPT-4, shows promise in addressing these challenges (OpenAI et al., 2023). Trained on vast amounts of text data, LLMs can generate human-like language and engage in natural conversation (W. X. Zhao et al., 2023), offering rich process-related domain knowledge (Gu et al., 2023). Their reasoning capabilities allow them to analyze and interpret textual data, potentially enabling them to understand process models and identify relationships within them (Huang & Chang, 2022). Research Paper P5 aims to explore how LLMs can enhance the interpretability of BPMN process models. The research investigates the following questions: *(1) How does the abstraction format affect model comprehension by LLMs? (2) Which prompting techniques best enhance comprehension? (3) How do different LLMs perform on this task? (4) Can such tools improve user comprehension in practical settings*?

To explore how LLMs can enhance process model comprehension, Research Paper P5 develops a conceptual framework and software artifact named AIPA (AI-powered Process Assistant). AIPA enables users to interact with BPMN models through natural language by integrating LLMs into the process of querying, interpreting, and explaining process structures. The system is designed to bridge the gap between technically formal process representations and the needs of non-expert users for intuitive, understandable insights. To achieve this, the study systematically investigates three core design dimensions: (1) the abstraction format used to present process models to the LLM, (2) the prompting strategy used to guide the model's responses, and (3) the choice of underlying language model. Figure 14 shows the architecture of the LLM-based process model comprehension framework. The process begins with a user uploading a BPMN model, which is automatically abstracted into a format suitable for LLM processing. Users can optionally select specific model parts for focused analysis. To support comprehension, the abstraction is enriched with tailored instructions and prompting strategies to guide the LLM. The user's inquiry is combined with the abstraction and prompts into a single input, which the LLM processes to generate a response. The system supports dynamic interaction: follow-up questions are added to the conversation history and included in updated prompts, allowing the LLM to provide context-aware responses.

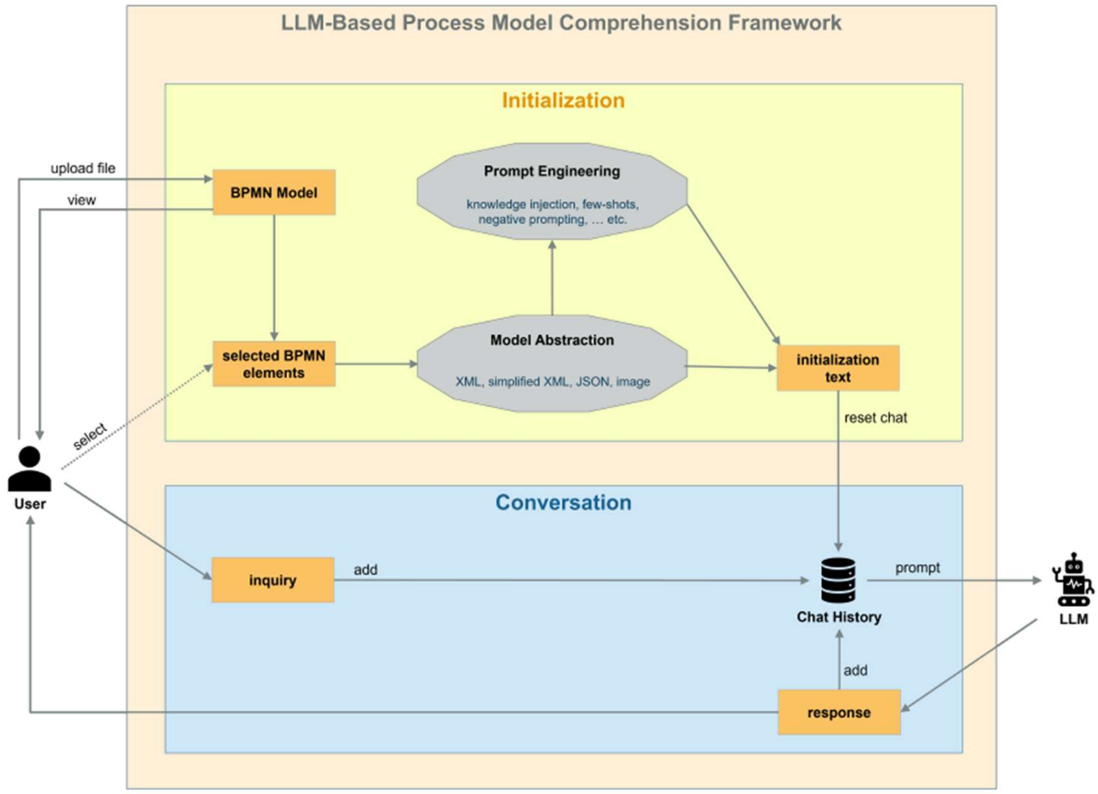


Figure 14 LLM-based process model comprehension framework

The abstraction of BPMN models is a crucial component of the framework, enabling their transformation into formats that can be effectively processed by LLMs. Research Paper P5 introduces four abstraction formats that translate a BPMN model into machine-readable representations for LLM processing: (1) raw XML, (2) simplified XML, (3) JSON, and (4) an image-based format processed via captioning models. Each format balances a trade-off between syntactic precision, token length, and cognitive accessibility. In addition, the study defines and tests seven prompting strategies: standard (S1), natural language reformulation (S2), pre-structured questions (S3), role prompting (S4), chain-of-thought (S5), few-shot prompting (S6), and negative prompting (S7). These strategies vary in how much context, structure, and behavioral guidance they provide to the LLM. The combination of abstraction and prompting defines the interface between BPMN model content and the LLM's interpretation capability. The resulting software artifact, AIPA, integrates these elements into a flexible architecture comprising three main components: (1) a BPMN input module that accepts user-uploaded process models, (2) an abstraction and prompting engine that transforms models and applies predefined strategies, and (3) a chat interface that relays user queries and model responses. The system was implemented with a modular backend supporting different LLM APIs, including

OpenAI's GPT-4o, WizardLM-2, and Mixtral-8x22B. AIPA is capable of processing user questions about the process model (e.g., control-flow logic, data dependencies, role responsibilities) and providing conversational responses derived from the structured input.

To evaluate the framework, the study follows a two-phase evaluation strategy combining automated benchmarking with a qualitative user study. In the first phase, an automated evaluation was conducted to benchmark LLM performance across multiple configurations. Three BPMN models of varying complexity and domain were selected. A total of nine distinct question types were defined, including control-flow questions (e.g., sequence, loops, conditions), data-flow questions, and actor-specific queries. Each question was posed to the LLM in a structured environment, with abstraction and prompting combinations varied systematically. Performance was assessed based on response accuracy, coherence, and completeness, using a combination of scoring rubrics and expert judgments. The results show that JSON and simplified XML abstractions led to significantly better performance compared to raw XML and image-based representations. These formats provided structured but lightweight data that LLMs could interpret with fewer tokens and less syntactic noise. Among prompting strategies, S3 (pre-structured questions), S6 (few-shot prompting), and S7 (negative prompting) proved most effective in eliciting coherent and actionable model explanations. These strategies offered the model both behavioral scaffolding and example-driven anchoring, reducing hallucinations and improving factual grounding. With respect to model performance, GPT-4o consistently outperformed WizardLM-2 and Mixtral-8x22B, especially on complex question types requiring contextual reasoning. It demonstrated greater robustness in maintaining coherence across multi-turn conversations and provided more actionable responses in cases involving ambiguous or incomplete model elements. WizardLM-2 and Mixtral-8x22B showed competitive performance on simpler questions but struggled with nested structures and implicit logic. These results confirm the need to align abstraction format, prompt strategy, and model capability for optimal comprehension outcomes.

In the second phase, a qualitative user study was conducted with six BPMN experts (consultants, analysts, and researchers) to assess AIPA's perceived value in real-world use. Participants were asked to interact with the tool on several uploaded process models and evaluate it according to a predefined set of eleven criteria, including soundness, clarity, completeness, conciseness, actionability, and interactivity. The evaluation drew on established IS quality frameworks and used a combination of Likert scales and open-ended feedback. The results of the user study indicate that AIPA was highly appreciated for its ability to translate complex BPMN content into understandable language. Experts praised the tool for its interactivity, semantic soundness, and breadth of understanding, noting that it facilitated exploratory dialogue with the process model – something traditional modeling tools do not offer. In particular, the combination of question prompting and real-time explanation enabled more intuitive navigation of large or unfamiliar models. However, participants also highlighted limitations. In several cases, answers were perceived as too verbose or repetitive. Some experts wished for visual grounding of responses within the model (e.g., highlighting relevant paths or roles in the diagram) and more control over verbosity and technical depth. Furthermore, some false assumptions in responses indicated the need for better grounding mechanisms, particularly when dealing with incomplete or inconsistent models. Despite these challenges, the overall impression was positive. AIPA was perceived as a valuable support tool for onboarding, training, and documentation purposes. The conversational interface was found to lower the barrier to understanding for non-experts, while also offering new affordances for expert users seeking rapid insights or scenario testing. The study concludes that while LLMs are not infallible, their integration into BPM tools opens up promising new avenues for model accessibility, cross-functional collaboration, and automated support in process-related tasks. Figure 15 shows an exemplary screenshot of the AIPA tool.

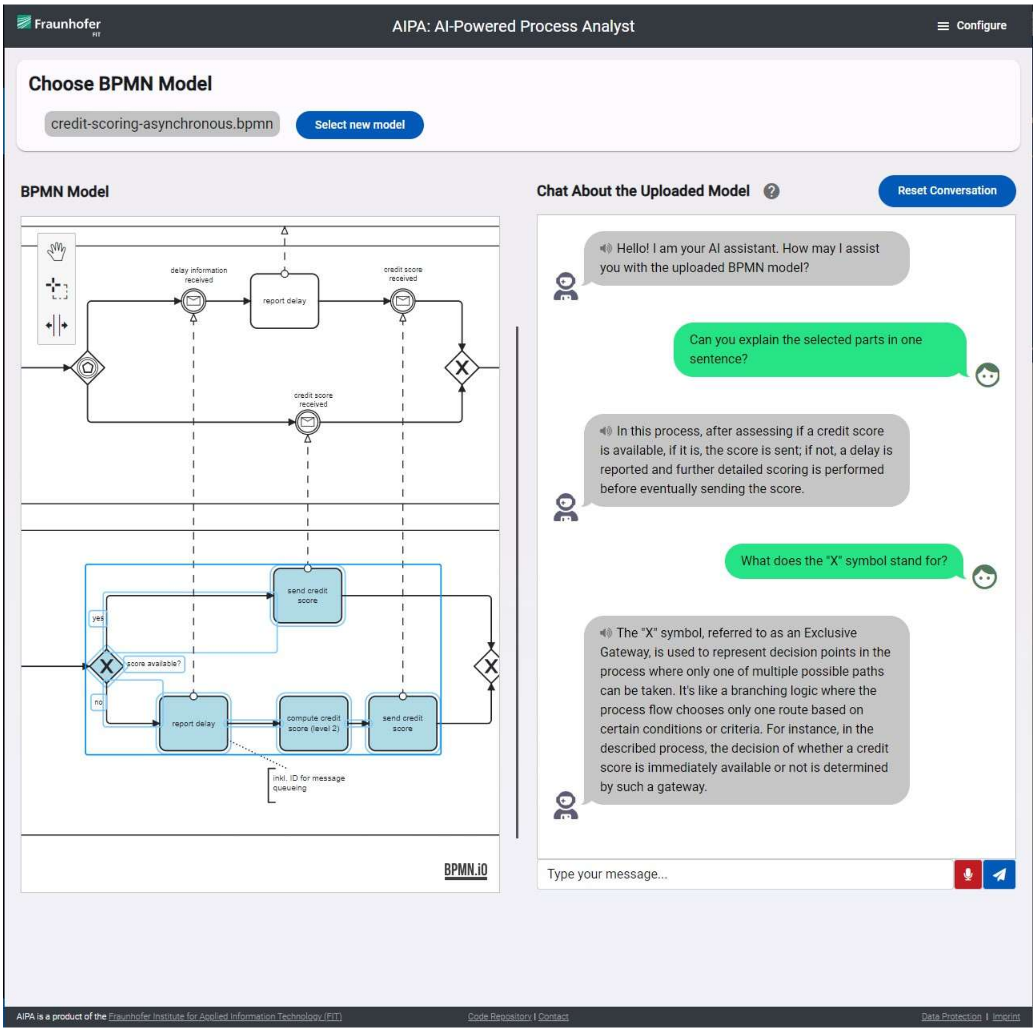


Figure 15 Screenshot of AIPA

Research Paper P5 contributes to the field of business process management by demonstrating how Large Language Models (LLMs) can be utilized to improve the accessibility and comprehension of BPMN process models. The study introduces a novel framework that combines four abstraction formats and seven prompting strategies to prepare BPMN models for LLM-based interpretation. This framework enables process models to be translated into machine-readable representations and queried interactively via natural language, thus making process logic more transparent for non-expert users. As a practical contribution, the paper presents the AIPA tool, a software tool that implements the framework and enables users to ask questions about BPMN models in a conversational interface. AIPA supports various abstraction formats (e.g., JSON, simplified XML) and incorporates prompting techniques such as few-shot learning, role prompting, and negative prompting. The tool is designed to help users explore and understand process structures without requiring modeling expertise. The study also provides a comprehensive evaluation of LLM performance across different abstraction and prompting combinations, comparing three leading models (GPT-4o, WizardLM-2, Mixtral-8x22B) and nine question types. In addition, a user study with BPMN experts highlights the strengths and limitations of the tool from a usability perspective. The findings offer actionable insights into the design of AI-assisted BPM tools and show how LLMs can be meaningfully integrated into process modeling environments to support understanding and communication.

Overall, Research Paper P5 contributes to the overarching goal of this dissertation by exploring how advanced AI capabilities - in this case, large language models - can enhance human understanding of complex process structures. By conceptualizing process model comprehension as a cognitive task and empirically evaluating the support potential of LLMs, the paper expands the notion of smartification toward augmentation rather than automation. The findings show that LLM-based explanations can significantly improve users' accuracy and confidence in interpreting process models, especially for non-expert users. Thus, the study illustrates how smart technologies can not only execute tasks but also foster cognitive empowerment. In doing so, it adds a complementary perspective to this dissertation's central argument: smartification requires both technical sophistication and human-centric design to unlock value in digitally augmented organizational environments.

IV Application of Smart Technologies in Business

While the previous chapters introduced conceptual foundations and design knowledge for smart technologies, this chapter examines how such technologies can be strategically applied and embedded in business contexts. Smart solutions alone do not guarantee business value - success depends on implementation conditions, readiness, and capability development. Research Paper P6 identifies key enablers and barriers of process digitalization projects, with a focus on socio-technical alignment and governance. Research Paper P7 complements this view by outlining four strategic pathways for SMEs in manufacturing to develop AI capabilities. Together, both studies provide empirical insights into how organizations can effectively translate smart technologies into business impact.

IV.1 Success Factors of Process Digitalization Projects

In recent years, digitalization has emerged as a transformative force reshaping societal structures and organizational practices (Beverungen et al., 2021). Fueled by the rapid development and adoption of digital technologies (DTs), digitalization creates a hyper-connected environment characterized by pervasive data availability, the convergence of physical and digital systems, and new forms of interaction between individuals, organizations, and smart objects (Daugherty, 2020; Gartner, 2020). While DTs range from established technologies such as cloud computing or analytics to emerging innovations like distributed ledger technologies, artificial intelligence, or extended reality, organizations continue to face challenges in translating technological potential into realized business value (Davenport & Westerman, 2018). Beyond the transformation of products into smart offerings (Beverungen et al., 2019; Huber et al., 2019), DTs offer substantial opportunities for the improvement and innovation of business processes (Mendling et al., 2020). They enable advanced forms of process automation, adaptive execution, and data-driven optimization (Kerpedzhiev et al., 2021). However, organizations often struggle to effectively integrate DTs into existing or novel processes, thereby limiting the impact of digitalization on operational efficiency and strategic advantage (Denner et al., 2018). Typically, such integration is carried out in the form of projects (Lehnert et al., 2016). Research Paper P6 refers to these initiatives as process digitalization projects (PDPs) that aim to improve business processes through the use of digital technologies. While existing literature provides tools and frameworks to identify potential digitalization ideas, guidance on how to successfully implement PDPs remains scarce. This gap exposes organizations to the risk of project failure, resulting in lost investments or impaired competitiveness. Although related domains such as business process management (BPM), project management (PM), and digital transformation research have proposed success factors for BPM programs or general transformation initiatives (Rosemann & vom Brocke, 2015; Trkman, 2010), these findings are fragmented and often not tailored to the specific characteristics of PDPs. Against this background, Research Paper P6 investigates the following research question: *Which factors drive PDP success?*

To identify and conceptualize the factors that drive the success of process digitalization projects (PDPs), Research Paper P6 adopts an exploratory, two-stage research approach combining a structured literature review with empirical data from expert interviews. Table 3 gives an overview of the research design. The study results in a consolidated list of 38 success factors (SFs) and proposes a PDP Success Model that links these factors to project success outcomes in terms of effectiveness and efficiency. In the first step, Research Paper P6 develops an ex-ante list of candidate success factors based on established models from adjacent domains such as IS, BPM, and project management (PM). Existing IS success frameworks (Aladwani, 2002; Alter, 2013; F. D. Davis, 1989; Petter et al., 2013; Rosemann & vom Brocke, 2015) were used to guide the initial categorization. Given the interdisciplinary and socio-technical nature of PDPs, the study synthesizes overlapping conceptual structures and aggregates them into seven overarching categories: strategy, structure, culture, people, process, project, and technology. Each category comprises success factors grounded in prior literature. In the second step, semi-structured interviews with 21 professionals involved in PDPs were conducted, all of whom worked in German manufacturing companies. The goal of this phase was to validate, refine, and extend the ex-ante list, accounting for the context-specific dynamics of digitalization projects in industrial environments. Through qualitative coding and interpretation of interview transcripts, the study identified seven entirely new success factors, and two previously identified factors were refined into three distinct ones. Additionally, 19 SFs from the ex-ante list were empirically confirmed, having been actively mentioned and discussed by interview participants. Conversely, nine factors from the original list were not confirmed through interviews, though they were retained in the overall model due to the exploratory nature of the research and the possibility that they might prove relevant in other contexts or industries. The result of this phase is an ex-post list of 38 success factors, which combines insights from both literature and empirical data. The structure of the list remains aligned with the seven-category framework, ensuring consistency and comparability. Examples of new SFs include factors related to rapid experimentation, adaptive governance structures, or cross-functional team autonomy - elements that reflect the dynamic and exploratory nature of PDPs.

#	Step	Action	Result
1	Literature review	Database search and systematic literature review	645 identified papers, 40 selected papers
2	Code extraction and building of the *ex-ante* list	Text analysis	1034 initial SF codes, 30 candidate SFs, 7 SF categories
3	Expert interviews	Semi-structured interviews with experts from real-world PDPs	21 interviewees with experts from 7 PDPs and 4 companies
4	Code extraction and building of the *ex-post* list	Interview analysis	7 additional candidate SFs, 2 refined candidate SFs resulting in 3 new ones, 9 SFs without supporting empirical evidence
5	Compilation of the *PDP Success Model*	Linking of independent and dependent variables	38 candidate SFs, 7 SF categories, 2 dependent variables

Table 3 Research Design

Building on this consolidated ex-post list, the final step was to construct the PDP Success Model which is shown in Figure 16. This model conceptualizes PDP success as a function of the identified success factors, linking them to two primary success outcomes: project effectiveness and project efficiency. These dimensions were selected based on their widespread acceptance in PM and BPM literature (Drucker, 2013; Fridgen et al., 2013) and their relevance to process change initiatives (Bandara et al., 2005; Schmiedel et al., 2020). The PDP Success Model visualizes the relationship between the 38 success factors (as independent variables) and the two success outcomes (as dependent variables). The model remains intentionally non-causal and does not assign weightings to individual factors but serves as a structured framework for guiding future research and practice. It reflects the understanding that PDP success is not driven by isolated elements but rather by the interplay of organizational, technological, and human-related enablers. The model's structure supports the modular application of success factors in different project environments and allows practitioners to assess which areas require strengthening or alignment for successful project outcomes.

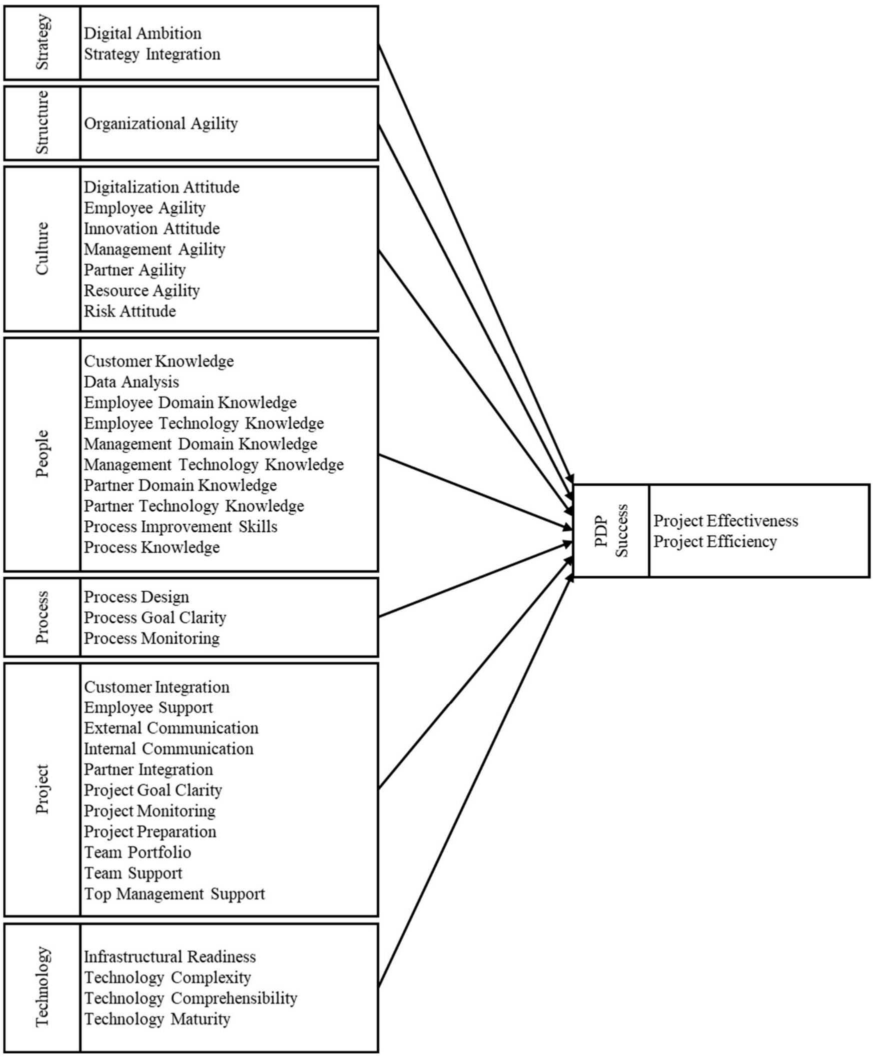


Figure 16 The PDP Success Model

Research Paper P6 contributes to the understanding of how organizations can successfully implement PDPs, which aim to improve or innovate business processes through the use of digital technologies. From a theoretical perspective, the study is the first to systematically integrate insights from BPM, PM, and digitalization literature to identify drivers of PDP success. It complements existing work that focuses on individual domains or specific aspects of process change by offering a broader, project-level view. Importantly, the study identifies ten SFs not previously discussed in the literature, such as digital ambition or partner agility, indicating that digitalization introduces new requirements for project success. Simultaneously, nine literature-derived SFs did not receive empirical support, suggesting a shift in what constitutes relevance under digitalization. From a managerial standpoint, the PDP Success Model provides a practical instrument for planning, assessing, and steering PDPs. It enables project teams to conduct fit/gap analyses, reflect on their strengths and weaknesses, and sensibly allocate limited resources. Moreover, it highlights the importance of overcoming legacy thinking and adapting existing PM routines to address the unique challenges and opportunities of digital transformation.

Overall, Research Paper P6 contributes to the overarching goal of this dissertation by highlighting organizational prerequisites for successfully applying smart technologies in practice. By identifying key success factors and barriers in PDPs, the paper emphasizes that smartification requires more than technical design - it depends on effective coordination, stakeholder alignment, and organizational maturity. The findings underscore the socio-technical nature of transformation initiatives and demonstrate that strategic and cultural conditions are critical for unlocking the potential of smart technologies. Thereby, the study complements the technological and design-oriented contributions of this dissertation with insights into the organizational foundations of smartification.

IV.2 Pathways to Developing AI Capabilities

Artificial Intelligence (AI) holds significant promise for transforming organizational operations (Ågerfalk et al., 2022; Berente et al., 2021), yet many firms – particularly small and medium-sized enterprises (SMEs) – struggle to realize its full potential (Åström et al., 2022; Berg et al., 2023). While large corporations increasingly integrate AI into their core activities, SMEs remain cautious, constrained by limited financial and human resources (Oberländer et al., 2021; Svahn et al., 2017). Although motivated to engage with AI, many SMEs lack the capabilities and strategic guidance necessary to deploy AI solutions at scale (Hansen et al., 2024; M. Weber et al., 2023). This challenge is particularly pronounced in the manufacturing sector, where AI adoption is viewed as a key driver of both economic performance and sustainability, but where AI initiatives remain scattered and localized (Åström et al., 2022; Stahl et al., 2023). Recent developments in digital manufacturing – such as the introduction of cyber-physical systems and the industrial Internet of Things – have led SMEs to accumulate large volumes of production, product, ambient, and consumption data (Papadopoulos et al., 2022; Raptis et al., 2019). However, most firms still struggle to extract actionable insights from this data. Many remain confined to descriptive analytics and are unable to leverage data for advanced recommendations or automated decision-making (Hunke et al., 2022; Stahl et al., 2023). This disconnect prevents SMEs from evolving toward data-driven business models and from building the foundational capabilities necessary for AI-enabled transformation (Hansen et al., 2024; Sjödin et al., 2021). While prior literature has extensively addressed AI adoption, implementation, and capability requirements, it lacks a nuanced understanding of how SMEs in manufacturing actually proceed to develop relevant AI capabilities in alignment with their specific strategic goals and organizational context. Against this background, Research Paper P7 investigates the following research question: *What pathways can SMEs in the manufacturing sector take to develop relevant AI capabilities?*

To address this question, Research Paper P7 presents a multiple case study across eight SMEs in the manufacturing sector, each of which has engaged in AI initiatives. Drawing on 22 semi-structured interviews and secondary data, the study synthesizes four distinct pathways for AI capability development: AI Ambassador Group, AI Ecosystem Alliance, AI Innovation Hub, and AI Venture Spin-off. These pathways differ along two core dimensions: the source of capability development – either organic (internal) or inorganic (external) – and the organizational setup of actors – either interdependent (embedded in existing structures or partnerships) or independent (operating autonomously). Each pathway represents a unique strategic approach that aligns with firm-specific objectives and organizational contexts. Figure 17 categorizes the eight cases along the two dimensions in a four-field pathway matrix.

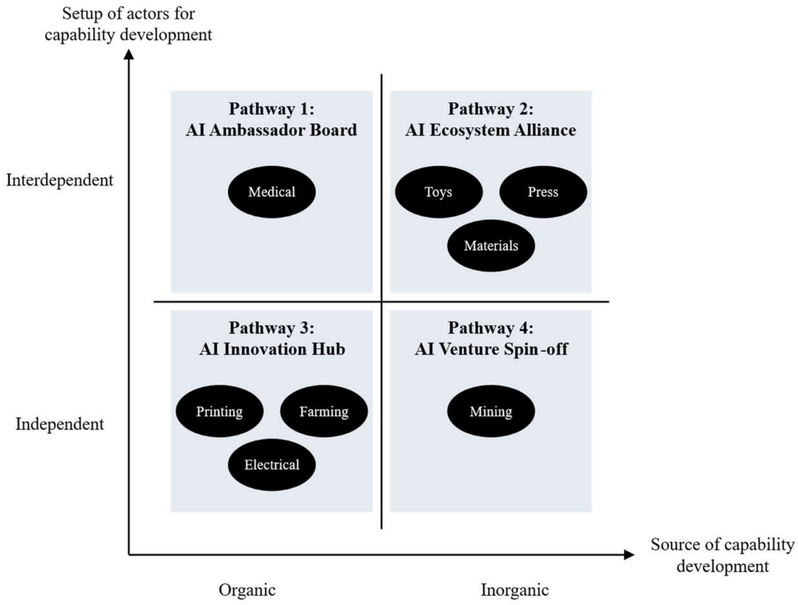


Figure 17 Four-field Pathway Matrix for AI Capability Development in SMEs in the Manufacturing Sector

With regard to the source of capability development, an AI Ambassador Group pursues an organic path to capability development and is characterized by a mutually dependent constellation of actors. A prime illustration is the medical case, which set up an internal task force to build relevant AI capabilities. The AI Ambassador Group is composed of a cross-functional team that unifies all AI-related efforts, thus advancing AI capability development in close coordination with core business activities. Second, an AI Ecosystem Alliance follows an inorganic strategy for capability development and is also marked by a mutually dependent actor structure. In this context, the glass, machinery, and toy cases entered into strategic partnerships with external collaborators to establish the necessary AI capabilities. In each instance, employees involved in these initiatives were members of an AI Ecosystem Alliance and contributed to the AI capability development process. Third, an AI Innovation Hub takes an organic route to capability development and is defined by an independent actor setup. The electrical, farming, and printing cases each launched internal units dedicated to advancing their AI capabilities. These efforts were driven by interdisciplinary teams that formed the core of the AI Innovation Hub and played a central role in capability development. Fourth, an AI Venture Spin-off adopts an inorganic model of capability development and is based on an independent actor structure. The mining case exemplifies this approach by establishing an external venture branch to foster the development of AI capabilities. This AI Venture Spin-off is comprised of employees who centralize all AI-related functions, enabling a capability development process that remains largely separate from day-to-day core business operations.

Across the four pathways, the study identified six core capability areas that define the process of AI capability development: strategy and leadership prioritization, processual and structural alignment, use case management, data and infrastructure setup, knowledge and skill building, and network and partnership engagement. While all SMEs address these areas, the specific activities and emphasis vary significantly across the four pathways. Table 4 presents an overview and detailed description of the six core capability areas. Moreover, Table 5 offers a comprehensive comparison of the four synthesized pathways, examining the rationale behind their selection, the speed and extent of AI capability development, and the key lessons derived from each pathway.

Capability Area	**Capability Description**
Strategy and Leadership Prioritization	… encompasses capabilities that sketch out how SMEs in the manufacturing sector shape the engagement and involvement of the management board. For SMEs, it is essential to ensure the provision of financial and personnel resources through the management board to steer the transformation process.
Processual and Structural Alignment	… relates to AI capabilities that illustrate how SMEs in the manufacturing sector manage the establishment and adjustment of the organizational hierarchy, framework, and network (i.e., operations and workflows), including the safe and secure use of AI applications. For SMEs, it is vital to establish new or redesign existing roles and responsibilities.
Knowledge and Skill Building	… encompasses AI capabilities that illustrate how SMEs in the manufacturing sector elevate the technical and non-technical proficiency of employees. For SMEs, it is vital to equip their employees with emerging competencies in the rapidly evolving technology landscape to enable informed engagement with AI.
Network and Partnership Engagement	… relates to AI capabilities that sketch out how SMEs in the manufacturing sector create collaborations with third-party entities to acquire or accumulate resources externally that are not present internally. For SMEs, it is essential to leverage external expertise to intensify and accelerate the exploration of AI, as their internal focus is often limited to the operation of the core business.
Use Case Management	… encompasses AI capabilities that sketch out how SMEs in the manufacturing sector discern and realize the most impactful AI use cases. For SMEs, it is vital to focus only on AI use cases that align with business objectives and deliver tangible benefits, as their room for experimentation and innovation activities is often limited due to resource constraints.

Data and Infra-structure Setup	… relates to AI capabilities that illustrate how SMEs in the manufacturing sector establish a robust technological framework to handle the development, deployment, and operation of AI in an efficacious manner. For SMEs, it is essential to build a technological foundation that allows the exploration but also the seamless embedding and integration of AI in the first place.

Table 4 Comparison of pathways for artificial intelligence capability development

Pathway	AI Ambassador Group	AI Ecosystem Alliance	AI Innovation Hub	AI Venture Spin-Off
Cases	Medical	Toys, Press, Materials	Electrical, Farming, Printing	Mining
Source	Organic	Inorganic	Organic	Inorganic
Setup	Interdependent	Interdependent	Independent	Independent
Rationale for Pathway Selection	- Strict data security regulations as well as legal and compliance requirements demand internal capability development. - Desire to consider the perspectives and advance the knowledge of employees on AI across functional domains requires an interdependent approach.	- Limited internal resources (e.g., technical expertise) necessitate external capability development with partners. - Decision to develop an AI strategy and identify AI use cases with employees across functional domains justifies an interdependent approach.	- High complexity of products and services as well as industry peculiarities inform internal capability development. - Decision to consolidate the disparate efforts with AI in a central unit justifies an independent approach.	- Primary focus on day-to-day business as well as CEO's belief in venture building guide external capability development in a venture arm. - Desire to decouple strategic deliberations on AI from day-to-day business requires an independent approach.
Speed of AI Capability Development	**Low** - Low pace, as the members of an AI Ambassador Group drive AI-related activities alongside their core work. - Absence of a solid technological data and infrastructure foundation restricts swift iterations and early success. - High bureaucratic constraints hinder agile decision-making.	**Medium** - Medium pace, as the support from external partners in an AI Ecosystem Alliance is continuous but not permanent. - Learning from best practices and success stories of external partners accelerates capability development. - Focus on single AI use cases and dependency on external partners slows down progress.	**Medium** - Medium pace, as the establishment of an AI Innovation Lab takes time until it works well and delivers actual value. - Assigning distinct roles and responsibilities as well as autonomy in decision-making accelerates capability development. - Focus on in-house development of AI use cases slows down progress.	**High** - High pace, as the employees of an AI Venture Spin-off drive AI-related activities full-time. - Presence of a solid technological data and infrastructure foundation enables swift iterations and rapid learning. - Low bureaucratic constraints allow for agile decision-making.
Scale of AI Capability Development	**Low** - Souring of ready-to-use and off-the-shelf AI solutions impairs transferability to other application areas and functional domains. - Resource constraints require a focus on a few AI use cases rather than a realization of multiple AI use cases at scale.	**Low** - Collaboration with external partners may have a technology-specific focus and relate to isolated application areas or specific functional domains that impair transferability. - Operating the core business and running competing IT projects hinder the exploration of AI use cases at scale.	**High** - In-house development of AI solutions allows synergies beyond isolated application areas or specific functional domains. - Solid technological data and infrastructure foundation support the organization-wide expansion of AI use cases.	**High** - Collaboration between internal departments and the venture arm ensures a smooth handover of AI solutions. - Strategic and visionary approach enables the scaling of AI across application areas and functional domains.

Key Learnings from Pathway Selection	- Have sponsors who can encourage the creation of structures for AI. - Focus on key AI use cases rather than doing a lot and getting nothing out of it. - Commit members to advance AI within the scope of their possibilities.	- Cultivate an understanding that AI is an opportunity rather than a threat. - Ensure that AI becomes a permanent topic beyond individual projects. - Use external partners as a starting point for future endeavors.	- Interact with specialized departments to identify purposeful AI use cases. - Allocate distinct roles and responsibilities for clear contact persons. - Recognize the importance of multipliers who advocate AI initiatives.	- Ensure understanding of the venture arm of the core business. - Build good communication practices with the IT department. - Recognize the value of AI as a driver for future success.

Table 5 Case Comparison

Research Paper P7 contributes to the ongoing discourse on AI capability development in SMEs by providing a comprehensive understanding of how firms in the manufacturing sector can systematically build the capabilities needed to harness AI's strategic potential. Addressing a significant gap in existing research, the study identifies and synthesizes four distinct pathways that SMEs can follow to develop AI capabilities in alignment with firm-specific objectives and organizational contexts. Theoretically, the study adds descriptive depth to emerging work on AI capability development by offering a nuanced, empirically grounded framework for understanding distinct strategic approaches. In doing so, it advances prior work on digital transformation pathways by providing a detailed lens specific to AI in SMEs. The synthesized pathways form a basis for future theorizing through explanation (Type II), prediction (Type III-IV), and design and action (Type V) theories, enabling researchers to examine the causal mechanisms, long-term outcomes, and design principles underpinning AI transformation efforts in SMEs. Practically, the study equips managers in SMEs with a structured decision-making toolkit for navigating AI transformation. The pathway framework and capability model support strategic deliberations on how to approach capability development – whether internally or externally sourced, integrated or decoupled – and guide the design of tailored development activities. Moreover, the results offer actionable insights for planning and monitoring the capability development process, from setting target states to defining specific action plans and progress indicators. Managers are empowered to reflect on their current trajectory, combine elements from different pathways, and derive value-driven roadmaps aligned with strategic goals. In this way, the study serves as both a theoretical foundation and a pragmatic guide for SMEs seeking to unlock AI's transformative potential.

Overall, Research Paper P7 contributes to the overarching goal of this dissertation by illustrating how organizations can build the foundational capabilities needed to realize the potential of smart technologies. By identifying four distinct pathways for AI capability development in SMEs, the study emphasizes that smartification is not a one-size-fits-all process, but must be aligned with organizational structures, resources, and strategic intent. The paper highlights that capability-building is both a technical and organizational challenge, requiring iterative learning and contextual adaptation. In doing so, it complements this dissertation's design-oriented and technical perspectives with strategic insights on how smartification can be practically enabled within diverse organizational settings.

V Conclusion

V.1 Summary

Smart technologies hold immense transformative potential for businesses, yet their successful integration into organizational practice remains challenging. Despite growing technological maturity, many companies struggle to embed smart technologies into core processes and products in a way that generates strategic value. Existing research has largely focused either on technical architectures or isolated business use cases, but often neglects the interplay between design, implementation, and organizational application. As a result, theoretical guidance is lacking on how smart technologies can be purposefully designed and deployed to enhance both process performance and product intelligence. In particular, we still lack a theoretical understanding of how interactions between smart technologies, individuals, and organizations are constituted and what characterizes technologies as "smart." Especially unclear is how smartness emerges from the dynamic interplay between human and technological actors, or how continuous technological advancement reshapes the action possibilities of smart systems. While technical capabilities of smart technologies are rapidly evolving, practitioners continue to face difficulties in designing solutions that transcend basic functionality and generate tangible impact. At the same time, organizations are increasingly challenged to align technical innovation with business value creation, highlighting the need for deeper insights into the design and implementation of smart technologies in organizational contexts.

This dissertation and the embedded research papers contribute to the identified gaps by advancing a comprehensive understanding of smart technologies across conceptual, design, and strategic dimensions. First, the dissertation establishes a conceptual foundation for analyzing the nature and evolution of smart technologies. By theorizing smartness in IS and examining the evolution of smart technologies, it contributes to a deeper understanding of the nature of smart technologies and how they evolve in organizational contexts. Second, the dissertation develops design knowledge for developing smart technologies in both process- and product-centric applications. It delineates how smart technologies can be purposefully realized and operationalized in both processes and products, thereby informing the ongoing discourse on smartification in IS design science. Third, the dissertation addresses the strategic application of smart technologies in business.

Drawing on empirical studies, it identifies success factors, capability development pathways, and integration strategies that help organizations align smart technology implementation with business value creation. Together, these contributions support both scholars and practitioners in conceptualizing, designing, and applying smart technologies in ways that generate sustainable organizational impact.

Section II (including Research Papers P1 and P2) contributes to a deeper conceptual understanding of smart technologies by clarifying how smartness emerges and evolves over time. Research Paper P1 introduces the concept of a "smart action" to theorize how smartness becomes manifest through socio-technical interaction patterns between human and technological actors. The resulting framework identifies recurring action patterns, actor roles, and information processing steps that jointly shape perceived smartness in digital contexts. Research Paper P2 builds on this foundation by theorizing the evolution of affordances in response to technological progress. It develops the Theory of Technology-Affordance-Evolution, which outlines three distinct patterns of affordance evolution across successive technology iterations. Together, these two research papers enrich the theoretical grounding of smart technologies by addressing both the micro-level constitution of smart interactions and the macro-level dynamics of affordance evolution. This conceptual groundwork supports the dissertation's overarching aim of explaining how smart technologies can be designed and deployed to reshape business processes and products in meaningful ways.

Section III (including Research Papers P3, P4, and P5) presents design-oriented research that advances the smartification of processes and products by providing actionable design guidance across varying domains and levels of technological sophistication. Research Paper P3 develops a process-oriented digital twin architecture tailored to industrial testing laboratories, demonstrating how smart technologies can enhance traceability, transparency, and responsiveness in highly regulated environments (process perspective). Research Paper P4 focuses on the development of a wearable IoT-based health system for bladder monitoring, introducing a set of behavior-sensitive design principles that integrate sensor fusion, real-time feedback, and individualized adaptation to support patient autonomy (product perspective). Research Paper P5 explores the potential of LLMs to augment human comprehension of business process models by enabling natural language interaction with BPMN structures (process perspective). Across these three papers, the section contributes to a nuanced understanding of how smart capabilities - ranging from automation and sensing to cognitive augmentation - can be purposefully embedded into processes and products. Collectively, these contributions illustrate how technical sophistication and human-centered design can be combined to unlock organizational value in digital innovation contexts.

Section IV (including Research Papers P6 and P7) advances the understanding of how smart technologies can be strategically applied and organizationally anchored to generate business value. While previous sections focused on conceptual and design-level contributions, this chapter highlights the organizational prerequisites and transformation pathways necessary for realizing the benefits of smartification in practice. Research Paper P6 investigates PDPs and synthesizes 38 success factors across seven categories to explain what enables or hinders digital transformation initiatives. The study introduces the PDP Success Model, which provides a structured framework for planning, assessing, and steering PDPs, thus addressing the socio-technical complexity of digital innovation. Research Paper P7 complements this view by examining how SMEs in the manufacturing sector can build AI capabilities. Through a multiple case study, the paper derives four strategic pathways – ranging from internal ambassador groups to external venture spin-offs – and outlines six key capability areas that guide AI transformation efforts. Together, both studies demonstrate that the effective use of smart technologies requires more than technical sophistication: it demands strategic alignment, organizational commitment, and capability development tailored to context-specific conditions. These contributions round out the dissertation by emphasizing that smartification is not solely a matter of design or implementation, but also of strategic integration into organizations.

In sum, this dissertation contributes to a deeper understanding of how smart technologies can be meaningfully conceptualized, effectively designed, and successfully applied in organizations. By integrating theoretical perspectives, design science approaches, and empirical insights from practice, it supports both researchers and practitioners in shaping the ongoing smartification of processes and products across domains.

V.2 Limitations and Future Research

The findings of this thesis must be considered in light of certain limitations, which also offer valuable impulses for future research. While the individual limitations of each research paper can be found in the respective articles (see Sections VI.3 to VI.9), this section consolidates and summarizes the overarching limitations of the dissertation. Thus, the following presents limitations and avenues for future research on investigating smart technologies.

First, the results of the research papers providing the conceptual foundation for understanding the nature of smart technologies (Section II) were established inductively based on systematic literature reviews and case studies. Accordingly, some limitations are inherent in the nature of these methodological approaches. Research Paper P1 is limited by its search strategy, which included selected IS journals and conferences and a focus on the search terms "smart" and "smartness" – potentially narrowing the conceptual scope of the analysis. In contrast, Research Paper P2 is primarily limited by its reliance on secondary data sourced from publicly available material. While suitable for identifying overarching affordance evolution patterns, this approach may benefit from complementary empirical data – such as interviews or surveys – to enrich and validate the identified mechanisms. Together, these limitations point to opportunities for future research to expand the theoretical and empirical grounding of smart technology studies. For Research Paper P1, promising directions include explanatory studies that investigate how smart actions are perceived and enacted across different contexts and observers. Case studies of real-world applications - especially those involving unexpected outcomes - can deepen understanding of how smartness manifests. Research Paper P2 highlights the need for empirical studies that go beyond secondary data to examine the micro-level interactions between users and technologies. In particular, future work could explore how affordances evolve through user engagement and how individual perceptions shape the actualization of smart technologies' affordances over time.

Second, while all three research papers in Section III provide detailed SAs and evaluate their artifacts in real-world settings, the nature of design-oriented research introduces inherent limitations. Specifically, the contextual scope, participant diversity, and scale of evaluation limit the generalizability of the findings. Research Paper P3 evaluates a digital twin in an industrial laboratory, but the focus on a single domain restricts insights into other laboratory types or sectors. Research Paper P4 demonstrates a wearable bladder monitoring system in a healthcare setting; however, the number of field study participants is limited to four patients due to the complexity of the hardware and the need for intensive, in-person onboarding. Research Paper P5 assesses an LLM-based assistant for process model comprehension through a user study with six BPM experts. While their expertise ensured high-quality feedback, the small sample size and the relatively homogeneous background of the participants constrain broader conclusions regarding usability across diverse user groups. Research Paper P3 invites follow-up studies across various laboratory types – such as medical or environmental labs – to validate and adapt the proposed design principles and architecture to diverse operational settings. Research Paper P4 highlights the need for larger-scale patient studies to assess the long-term effectiveness of the wearable monitoring solution. Future studies should include extended usage periods and enable system adaptation based on individual physiological data to ensure personalized and sustained use. Research Paper P5 offers promising directions by proposing the integration of large language models with process mining techniques, enabling automated interpretation of discovered process models and closing the loop between formal modeling and real-world execution. These directions collectively aim to enhance the robustness, transferability, and real-world relevance of smart technologies for processes and products.

Third, the research papers in Section IV provide valuable insights into the strategic and organizational integration of smart technologies; however, they are inherently shaped by methodological choices that may limit the generalizability of their findings. Although literature reviews, expert interviews, and case studies offer rich, practice-oriented perspectives, they are also subject to biases arising from the specific selection of sources, interviewees, and cases. Research Paper P6 draws on interviews within the manufacturing sector and focuses exclusively on business-to-business process digitalization projects. This deliberate scope supports depth but limits the applicability of findings to other sectors or business models. Research Paper P7 synthesizes insights from eight SME cases to identify pathways for AI capability development. While these cases provide valuable insights into strategic development pathways, the identified patterns reflect the characteristics of the examined organizations - such as their industry setting, digital maturity, and position within the value chain. As such, results derived from different organizational contexts may vary. Hence, future research should further validate and expand the findings by exploring a broader range of organizational settings and business models. For Research Paper P6, this includes applying the success factor model for process digitalization projects in domains beyond manufacturing and in business-to-consumer contexts, as well as examining success criteria for more explorative digitalization efforts. Research Paper P7 encourages further empirical testing of the four AI capability development pathways across diverse industries, organizational sizes, and positions in the value chain to assess their robustness and refine their applicability. Together, these efforts can enhance the contextual understanding and generalizability of strategic approaches to the application of smart technologies in business.

Notwithstanding the above limitations, I am confident that this dissertation contributes to the current body of knowledge and will guide scholars and practitioners in understanding and performing the operational, methodological, and managerial practices associated with the effective application of smart technologies in business.

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VII Appendix

VII.1 Index of Research Papers

Research Paper P1: The Concept of a Smart Action – Results from Analyzing Information Systems Literature

Huber R.X.R., Lockl J., Röglinger M., Weidlich R. (2024). The Concept of a Smart Action – Results from Analyzing Information Systems Literature. In: *Communications of the Association for Information Systems*. DOI: 10.17705/1CAIS.05408
(VHB-Rating 2024: B)

Research Paper P2: What's Next? Toward a Theory of Technology-Affordance-Evolution

Lockl A., Lockl J., Oberländer A.M., Weidlich R. (2025). What's Next? Toward a Theory of Technology-Affordance-Evolution. Second Revision: *IEEE Transactions on Engineering Management*.
(VHB-Rating 2024: B)

Research Paper P3: Designing a Process-oriented Digital Twin for Industrial Testing Laboratories

Weidlich R., Albrecht T., Derr P., Röglinger M. (2024). Designing a Process-oriented Digital Twin for Industrial Testing Laboratories. In: *IEEE Transactions on Engineering Management*. DOI: 10.1109/TEM.2024.3481670
(VHB-Rating 2024: B)

Research Paper P4: Designing a wearable IoT-based bladder level monitoring system for neurogenic bladder patients

Jonas C., Lockl J., Röglinger M., Weidlich R. (2023). Designing a wearable IoT-based bladder level monitoring system for neurogenic bladder patients. In: *European Journal of Information Systems*. DOI: 10.1080/0960085X.2023.2283173
(VHB-Rating 2024: A)

Research Paper P5: Leveraging Large Language Models for Enhanced Process Model Comprehension

Kourani H., Berti A., Hennrich J., Kratsch W., Weidlich R., Li C., Arslan A., van der Aalst W., Schuster D. (2026). Leveraging Large Language Models for Enhanced Process Model Comprehension. In: *Decision Support Systems*. DOI: 10.1016/j.dss.2025.114563
(VHB-Rating 2024: B)

Research Paper P6: Success factors of process digitalization projects – insights from an exploratory study

Baier M.S., Lockl J., Röglinger M., Weidlich R. (2022). Success factors of process digitalization projects – insights from an exploratory study. In: *Business Process Management Journal*. DOI: 10.1108/BPMJ-07-2021-0484
(VHB-Rating 2024: C)

Research Paper P7: Pathways to Developing Artificial Intelligence Capabilities: Insights from Small and Medium-sized Enterprises in the Manufacturing Sector

Meierhöfer S., Oberländer A.M., Weidlich R. (2025). Pathways to Developing Artificial Intelligence Capabilities: Insights from Small and Medium-sized Enterprises in the Manufacturing Sector. First Revision in: *Information & Management*.
(VHB-Rating 2024: B)

VII.2 Individual Contribution to the Included Research Papers

This cumulative doctoral thesis includes seven research papers. All research papers were written in collaboration with multiple co-authors. This section outlines the settings and describes my individual contribution to each of the seven papers.

Research Paper P1 entitled "*The Concept of a Smart Action – Results from Analyzing Information Systems Literature*" (Huber et al. 2024; Section II.1) was written together with three co-authors. I had a key role in most parts of the research project. I contributed significantly to conducting the literature review and developing the resulting conceptual model. Additionally, I was responsible for theoretically embedding the resulting framework into existing theories. In terms of writing, I was responsible for the original drafting and for reviewing and editing the entire paper.

Research Paper P2 entitled "*What's Next? Toward a Theory of Technology-Affordance-Evolution*" (Lockl et al. 2025; Section II.2) was written together with three co-authors. I had a crucial role in all parts of the research project. I contributed significantly to formulating the overarching research goals and designing the research methodology of the project. I also engaged in the development of the resulting theoretical framework as well as in the synthesis and presentation of the research results. In addition, I was responsible for drafting multiple sections of the manuscript and was involved in reviewing and editing the entire paper.

Research Paper P3 entitled "*Designing a Process-oriented Digital Twin for Industrial Testing Laboratories*" (Weidlich et al. 2024; Section III.1) was written together with three co-authors. In line with my role as the lead author, I was responsible for the conceptualization and administration of the research project. I designed the research approach and developed the resulting design principles and software architecture. I also led the iterative evaluation process and the preparation and presentation of results. Finally, I was responsible for the original drafting of the manuscript and was involved in the review and editing of the entire research paper. Although I am the lead author of this paper, the three co-authors were involved in all parts of the project and were instrumental in advancing our contribution.

Research Paper P4 entitled "*Designing a wearable IoT-based bladder level monitoring system for neurogenic bladder patients*" (Jonas et al. 2023; Section III.2) was written together with three co-authors. I had a crucial role in all parts of the research project. I contributed significantly to the conceptualization of the project and to the design of the research methodology. I contributed significantly to the conceptualization of the project and to the design of the research methodology. In addition, I was responsible for developing the design principles and the resulting software architecture. Furthermore, I conducted the evaluation of the study's results. In terms of writing, I was responsible for the original drafting and was involved in reviewing and editing the entire paper.

Research Paper P5 entitled "*Leveraging Large Language Models for Enhanced Process Model Comprehension*" (Kourani et al. 2025; Section III.3) was written together with nine co-authors. I had a crucial role in all parts of the research project. I contributed significantly to the testing and evaluation of the resulting prototype. Specifically, I developed the process models used to evaluate the prototype and conducted a user study with experts from practice to evaluate the usability of the artifact. In terms of writing, I was responsible for the original drafting of individual sections and was involved in reviewing and editing the entire paper.

Research Paper P6 entitled "*Success factors of process digitalization projects – insights from an exploratory study*" (Baier et al. 2022; Section IV.1) was written together with three co-authors. I had a crucial role in selected parts of the research project. I contributed significantly to the presentation of the research results and to the design of the research methodology. In addition, I was responsible for developing the theoretical contribution and managerial implications for the paper. In terms of writing, I was responsible for the original drafting of individual sections and was involved in reviewing and editing the entire paper.

Research Paper P7 entitled "*Pathways to Developing Artificial Intelligence Capabilities: Insights from Small and Medium-sized Enterprises in the Manufacturing Sector*" (Meierhöfer et al. 2025; Section IV.2) was written together with two co-authors. I had a crucial role in all parts of the research project. I contributed significantly to the conceptualization of the project and to the design of the research methodology. In addition, I was involved in conducting the multiple case study and in developing the resulting theoretical framework. In terms of writing, I was responsible for the original drafting of individual sections and was involved in reviewing and editing the entire paper.

VII.3 Research Paper P1: The Concept of a Smart Action – Results from Analyzing Information Systems Literature

Authors:

Huber R.X.R. · Lockl J. · Röglinger M. · Weidlich R.

Published in:

Communications of the Association for Information Systems (2024)

Abstract:

In recent years, the term 'smartness' has entered widespread use in research and daily life. It has emerged with various applications of the Internet of Things, such as smart homes and smart factories. However, rapid technological development and careless use of the term mean that, in information systems (IS) research, a common understanding of smartness has not yet been established. And while it is recognized that smartness encompasses more than the use of impressive information technology applications, a unified conceptualization of how smartness is manifested in IS research is lacking. To this end, we conducted a structured literature review applying techniques from Grounded Theory. We found that smartness occurs through actions, in which smart things and individuals interact, process information, and make data-based decisions that are perceived as smart. Building on these findings, we propose the concept of a 'smart action' and derive a general definition of smartness. Our findings augment knowledge about how smartness is formed, offering a new perspective on smartness. The concept of a smart action unifies and increases understanding of 'smartness' in IS research. It supports further research by providing a concept for describing, analyzing, and designing smart actions, smart devices, and smart services.

Keywords:

Smartness · Smart Action · Smart Thing · Internet of Things · Digital Technologies · Literature Review · Grounded Theory

VII.4 Research Paper P2: What's Next? Toward a Theory of Technology-Affordance-Evolution

Authors:

Lockl A. · Lockl J. · Oberländer A.M. · Weidlich R.

Second Revision in:

IEEE Transactions on Engineering Management

Extended Abstract:

As technological innovation accelerates, it becomes increasingly important to align evolving technological possibilities with user goals to create value for individuals and organizations (Steffen et al., 2019; Vassilakopoulou et al., 2023). Understanding the intertwined development of technological progress and technology use is essential for realizing the full impact of technological innovations (Li et al., 2025). Prior research stresses that a single point in time is insufficient to capture the events leading to technological outcomes (Lanamäki et al., 2020). Thus, past technology use is key to anticipating future use and developments.

Affordance theory provides a powerful lens for explaining how users perceive and actualize the action possibilities offered by technological artifacts (Markus & Silver, 2008; Seidel et al., 2013). Existing research has examined the perception and actualization of affordances (Zheng & Yu, 2016), their integration in IT artifacts (Strong et al., 2014), and the interplay of multiple affordances (Fayard & Weeks, 2014). Thapa and Sein (2018) introduced the "trajectory of affordances," showing how the actualization of affordances within a single technology iteration can give rise to new ones.

However, technological progress suggests that the emergence of new affordances is not only shaped by prior actualizations within a single iteration but can also unfold across multiple generations of a technology. For instance, the evolution from telephones to mobile phones and eventually to smartphones raises questions about whether affordances persist, change, or reappear in new contexts. Focusing solely on a technology's latest iteration risks overlooking important interrelations with earlier stages and limits explanatory and predictive power.

This study argues for an iteration-spanning perspective on affordance evolution that accounts for stepwise technological progress. Without such a view, affordance research risks incomplete understanding, weakened explanatory insights, and limited practical guidance. Against this backdrop, this study investigates the following research question: *How does affordance evolution unfold in the course of technological progress?*

To address this research objective, this study develops and demonstrates three theoretical patterns of technology–affordance evolution, extending the trajectory of affordances proposed by Thapa and Sein (2018). Pattern I, *technology-driven affordance evolution*, and Pattern II, *non-consecutive technology-driven affordance evolution*, describe how affordances evolve across successive or non-adjacent technology iterations. Pattern III, *affordance elimination and re-emergence*, illustrates how technological progress may simultaneously introduce new affordances while eliminating or later reviving existing ones. To demonstrate these patterns, the study analyzes the technological concept of the metaverse, which has undergone significant development across multiple technological generations.

The findings of this study yield important theoretical contributions. First, it introduces a theory of technology–affordance evolution, extending Thapa and Sein's (2018) work by integrating the role of technological progress into explanations of affordance development. Second, it contributes a theory for explanation (Gregor, 2006) that clarifies how affordances emerge, disappear, and re-emerge over time. These contributions provide valuable implications for research and practice, offering a foundation for contextualizing affordances within a technology's historical development and highlighting the importance of considering affordance elimination and re-emergence when analyzing technological innovations.

Keywords:

Affordances · Affordance Evolution · Affordance Theory · Affordance Trajectory · Emerging Technologies · Metaverse · Theory Building

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VII.5 Research Paper P3: Designing a Process-oriented Digital Twin for Industrial Testing Laboratories

Authors:

Weidlich R. · Albrecht T. · Derr P. · Röglinger M.

Published in:

IEEE Transactions on Engineering Management (2024)

Abstract:

Digital twins have gained significant attention in recent years as a means to represent physical objects digitally. It is now applied for planning, monitoring, and decision-making across various domains. While extensively leveraged in manufacturing, digital twins also present promising opportunities in other process-intensive sectors, such as the testing, inspection, and calibration industry. Industrial testing laboratories face challenges like cost pressures and efficiency demands, operating within a complex socio-technical and highly regulated environment. Current digital solutions, such as Laboratory Information Management Systems (LIMS), fall short of providing a comprehensive data and process management perspective and do not fully comply with the ISO/IEC 17025 standard, which ensures trust in laboratory operations and results. This paper aims to address these gaps by proposing a set of design principles (DPs) and a software architecture (SA) for a process-oriented digital lab twin developed through a design science research (DSR) approach. The artifact is evaluated through expert interviews, a prototypical implementation, and a field study in an industrial laboratory setting. The findings offer valuable insights for designing digital twins in laboratory process management, guiding future research and practical applications.

Keywords:

Design science research · Design principles · Digital twin · Industry 4.0 · Software Architecture · Testing laboratory

VII.6 Research Paper P4: Designing a Wearable IoT-based Bladder Level Monitoring System for Neurogenic Bladder Patients

Authors:

Jonas C. · Lockl J. · Röglinger M. · Weidlich R.

Published in:

European Journal of Information Systems (2024)

Abstract:

Over the last years, the use of Internet of Things (IoT) systems in healthcare has increased due to technological advancements and increased availability of data. Sensor-based monitoring of physiological parameters, in particular, promises rich opportunities to promote overall health and self-management of patients suffering from chronic diseases. As such, neurogenic bladder patients lack sensation and control over their bladder while they could regain sovereignty over their bladder management through monitoring their physiological parameters. In this paper, we aim to develop a wearable IoT-based bladder level monitoring system for managing neurogenic bladder dysfunctions. We develop a set of design principles taking a stance from behaviour theory and implement the design principles in a software architecture following a design science research approach. Further, we evaluate and revise the developed artefact and implement a proto-type of the software architecture. Our research contributes to IS research through prescriptive knowledge for IoT-based bladder level monitoring systems that can be transferred and generalised to similar areas of application. Further, we con-tribute to behaviour theory as we theorise a new type of trigger that we call a hybrid trigger.

Keywords:

Design Science Research · Internet of Things · Healthcare · Design Principles · Neurogenic Bladder

VII.7 Research Paper P5: Leveraging Large Language Models for Enhanced Process Model Comprehension

Authors:

Kourani H. · Berti A. · Hennrich J. · Kratsch W. · Weidlich R. · Li C. · Arslan A. · van der Aalst W. · Schuster D.

Published in:

Decision Support Systems (2026)

Abstract:

In Business Process Management (BPM), effectively comprehending process models is crucial yet poses significant challenges, particularly as organizations scale and processes become more complex. This paper introduces a novel framework utilizing the advanced capabilities of Large Language Models (LLMs) to enhance the comprehension of complex process models. We present different methods for abstracting business process models into a format accessible to LLMs, and we implement advanced prompting strategies specifically designed to optimize LLM performance within our framework. Additionally, we present a tool, AIPA, that implements our proposed framework and allows for conversational process querying. We evaluate our framework and tool through: i) an automatic evaluation comparing different LLMs, model abstractions, and prompting strategies; ii) a qualitative analysis assessing the ability to identify critical quality issues in process models; and iii) a user study designed to assess AIPA's effectiveness comprehensively. Results demonstrate our framework's ability to improve the comprehension and understanding of process models, pioneering new pathways for integrating AI technologies into the BPM field.

Keywords:

Process Model Comprehension · Business Process Management · Large Language Models · Generative AI

VII.8 Research Paper P6: Success Factors of Process Digitalization Projects – Insights from an Exploratory Study

Authors:

Baier M.S. · Lockl J. · Röglinger M. · Weidlich R.

Published in:

Business Process Management Journal (2022)

Abstract:

Purpose – Digitalization substantially impacts organizations, which increasingly use digital technologies to improve and innovate their business processes. While there are methods and tools for identifying process digitalization ideas and related projects (PDPs), guidance on the successful implementation of PDPs is missing. Hence, we set out to explore PDP success factors.

Design/methodology/approach – In an exploratory approach, we conducted a structured literature review to extract candidate PDP success factors from the literature on business process management, project management, and digitalization. After that, we validated, refined, and extended these intermediate results through interviews with 21 members of diverse PDP teams. Finally, we proposed the PDP Success Model by linking the candidate success factors with relevant success criteria.

Findings – The PDP Success Model covers 38 PDP success factor candidates, whereof 28 are already backed by the literature and ten have emerged during the interviews. Furthermore, the success factors are structured according to seven categories from the literature covering a broad range of socio-technical topics (i.e., strategy, structure, culture, people, process, project, and technology) as well as equipped with preliminary success rationales.

Originality – Our work is the first to systematically explore PDP success factors. The PDP Success Model shows that PDPs require a unique set of success factors, which combine established and hitherto underrepresented knowledge. It extends the knowledge on business process management and serves as foundation for future (confirmatory) research on business process digitalization and the successful implementation of PDPs.

Keywords:

Business Process Management · Digitalization · Success Factors · Literature Review · Exploratory Interviews

VII.9 Research Paper P7: Pathways to Developing Artificial Intelligence Capabilities: Insights from Small and Medium-sized Enterprises in the Manufacturing Sector

Authors:

Meierhöfer S. · Oberländer A.M. · Weidlich R.

First Revision in:

Information & Management

Extended Abstract:

Artificial intelligence (AI) has sparked substantial attention among researchers and practitioners (Ågerfalk et al., 2022; Benbya et al., 2020). Although the business potential of AI is widely acknowledged, many organizations still struggle to translate AI investments into tangible value (Åström et al., 2022; Berg et al., 2023). This challenge is particularly pronounced for small and medium-sized enterprises (SMEs), which have so far implemented AI initiatives only to a limited degree (Peretz-Andersson et al., 2024). Compared to large corporations, SMEs face constrained financial and human resources that hinder the adoption and scaling of digital technologies such as AI (Oberländer et al., 2021; Svahn et al., 2017). At the same time, disruptive AI-enabled success stories from major technology firms heighten competitive pressure on SMEs, making the development of AI capabilities essential for creating new products, delivering smart services, or designing innovative business models (Hansen et al., 2024; Weber et al., 2023).

In recent years, many SMEs – particularly in the manufacturing sector – have begun digitalizing their production environments within the broader shift toward Industry 4.0 (Lasi et al., 2014). Through the adoption of cyber-physical systems and the industrial Internet of Things, these firms have increasingly invested in sensors, connected machines, and interoperable systems, resulting in large volumes of machine, product, ambient, and consumption data (Papadopoulos et al., 2022). While many SMEs are able to generate descriptive insights from this data, they still struggle to leverage it for predictive or prescriptive analytics, thereby limiting their ability to enhance or innovate value propositions (Hunke et al., 2022; Stahl et al., 2023).

Given the rapidly expanding performance and scope of AI (Ågerfalk et al., 2022; Berente et al., 2021), SMEs could benefit substantially from AI-enabled improvements in productivity and sustainability, particularly in resource- and energy-intensive manufacturing environments (Leuthe et al., 2024). Accordingly, first AI initiatives are emerging in SMEs to explore individual use cases (Vial et al., 2023), and turning such use cases into practical applications has become a strategic priority for manufacturing executives (Bain & Company, 2024). However, to scale AI initiatives across functions and application areas, SMEs must build relevant AI capabilities (Hansen et al., 2024). Although the literature provides clarity on what these capabilities are, it remains unclear how SMEs can develop them in line with their specific objectives and organizational contexts (Ritala et al., 2024). As a result, SMEs pursue diverse pathways – i.e., strategic actions undertaken to develop AI capabilities – but systematic knowledge about such pathways is scarce (Keller et al., 2022; Soh et al., 2023).

Despite extensive research on AI adoption and implementation (e.g., Lee et al., 2023; Merhi, 2023), on AI-related capabilities (e.g., Hansen et al., 2024; Sjödin et al., 2021), and on digital transformation in SMEs (e.g., Ghobakhloo & Iranmanesh, 2021; Omrani et al., 2024), little is known about the pathways SMEs can take to develop relevant AI capabilities. This gap poses challenges for researchers seeking to understand the motives and logics behind such pathways and for practitioners aiming to disseminate AI initiatives across their organizations. Against this backdrop, this study investigates the following research question: *What pathways can SMEs in the manufacturing sector take to develop relevant AI capabilities?*

To address this research objective, this study provides a multiple case study and synthesizes qualitative data from eight SMEs in the manufacturing sector that are currently undergoing digital transformation through the strategic use of AI. Drawing on 22 semi-structured interviews with subject matter experts and complementary secondary data, this study identifies four pathways – AI Ambassador Group, AI Ecosystem Alliance, AI Innovation Hub, and AI Venture Spin-off – that represent distinct approaches to developing AI capabilities depending on the source of capability development and the configuration of actors involved. Each pathway reflects a unique mode of aligning AI capability development with firm-specific objectives and organizational contexts.

Based on these pathways, this study describes the development of AI capabilities across six core areas: processual and structural alignment, use case management, data and infrastructure setup, strategy and leadership prioritization, knowledge and skill building, and network and partnership engagement. This structured lens offers a first step toward advancing understanding of AI capability development in SMEs.

From a theoretical perspective, the pathways provide descriptive knowledge that enriches the discourse in information systems and strategic management on how SMEs can progress toward leveraging the business potential of AI. They offer a foundation for researchers to further theorize about the strategic use of AI through higher-level explanatory, predictive, or design-oriented theories. From a practical perspective, the pathways support managers in structuring strategic decisions on how to develop AI capabilities in alignment with organizational goals and contextual conditions.

Keywords:

Artificial Intelligence · Capability Development · Manufacturing · Pathways · Small and Medium-sized Enterprises

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