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Knowledge management and SMEs' digital transformation: A systematic literature review and future research agenda

Shahid Hafeez [a,b,*], Khuram Shahzad [a,b], Petri Helo [a], Muhammad Faraz Mubarak [c,d]

[a] School of Technology and Innovations, University of Vaasa, Wolffintie 32, 65200 Vaasa, Finland
[b] Innovation and Entrepreneurship InnoLab, University of Vaasa, Yliopistonranta 2, 65200 Vaasa, Finland
[c] Faculty of Computer Science, Dalhousie University, Halifax, Nova Scotia, Canada
[d] Faculty of Economics and Management, Vytautas Magnus University, Kaunas, Lithuania

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ABSTRACT

This study aims to identify and explain different collaborative approaches, delineate external actors' roles, and examine the interplay between knowledge exploration and exploitation processes for digital transformation. We conducted a search of academic papers using research terms such as "Digital*, Digital transfor*, industry 4.0 (I4.0), industry 5.0, knowledge exploration, knowledge acquisition, ecosystem collaboration*, knowledge networks, and open innovation" in both the Scopus and Web of Science databases. Altogether, 108 papers met the criteria (e.g., ABS 2 & 2+ ranking of journals, only journal papers, and focusing on small- and medium-size enterprises (SMEs) digital transformation) for conducting a systematic literature review in this research. The results indicate that external actors play specific roles in supporting SMEs' digital transformation. We found that customers and suppliers push and encourage SMEs in their digital transformation, while coopetition can elicit greater technological benefits for SMEs with close technological and economic proximity. Intermediaries provide knowledge-brokering services, facilitate innovation processes, and enable technology transfer and capacity-building for SMEs' digital transformation. Government initiatives, such as favorable policymaking and financial support, are important in promoting and facilitating a collaborative environment for technology development among SMEs. This study's results present two distinct collaborative mechanisms that SMEs can utilize for digital transformation: (I) core value chain and network actors' collaborations, which provide linear processes for knowledge exploration and exploitation, and (II) ecosystem and innovation platform-based collaborations, in which SMEs adopt the ambidextrous approach as a nonlinear process for knowledge exploration and exploitation for digital transformation. Certain organizational-level factors (organizational capabilities, micro-foundations, operational capabilities, organization strategies, and culture) are important for SMEs' knowledge exploitation in digital transformation. The study also presents an integrated framework and offers directions for future research and important insights for practitioners.

Introduction

SMEs are responsible for large-scale employment and contribute significantly to most countries' GDP (Kumar et al., 2020). During the last two decades, various exogenous external shocks have caused disruptions in the contemporary business environment. Due to flexible and agile organizational structures, SMEs are better at adapting to such disruptions (Chan et al., 2019). However, they face various challenges in their innovation processes, e.g., limited internal R&D capabilities, resource limitations, and a tendency to focus on short-term economic benefits (Madrid-Guijarro et al., 2009). Recent digital waves have posed new challenges for SMEs to conFig. ways to implement and utilize digital technologies in their business processes, offerings, and business models (Kumar et al., 2020). Digital technologies are changing the competitive landscape at a breakneck pace (Mahmood et al., 2020). Effective utilization of digital technologies leads organizations to have superior organizational performance and outpace their competitors. Thus, implementation and utilization of digital technologies are becoming indispensable for SMEs to achieve process efficiency, reduce operating costs, achieve sustainability targets, develop new products, offer new

* Corresponding author.
E-mail addresses: shahid.hafeez@uwasa.fi (S. Hafeez), khuram.shahzad@uwasa.fi (K. Shahzad), petri.helo@uwasa.fi (P. Helo), m.mubarak@dal.ca (M.F. Mubarak).

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services (Pfister & Lehman, 2023), and create digitally enabled product-service systems (Gao et al., 2023). Therefore, digital transformation is defined as "SMEs' progression from converting firm processes to digital form to integrating digital technologies into products and services, and finally, transforming entire business models" (Soluk & Kammerlander, 2021).

Considering rapid technological advancements, researchers study organizational factors (e.g., culture, innovation strategies, leadership, social capital) (Khin & Kee, 2022), micro-foundations (Christofi et al., 2024), dynamic capabilities (Del Giudice et al., 2021), and knowledge management systems (AL-Khatib et al., 2024) related to the digital transformation of SMEs. Similarly, various theoretical frameworks have been utilized to examine digital transformation, including the resource-based view (Chung & Kim, 2023; Radic et al., 2019), the dynamic capabilities framework (Scuotto et al., 2023), the technology-organization-environment framework (Shukla & Shankar, 2022), and the knowledge-based view (Comacchio et al., 2012; Ricci et al., 2021; Yao et al., 2020). Although these frameworks provide valuable insights, the knowledge-based view (KBV) has recently gained popularity among information systems and innovation management researchers. The primary factor contributing to KBV acceptability is the ability of the framework to elucidate the critical nature of external and internal technological knowledge management for the digital transformation (Haug et al., 2023; Ricci et al., 2021). Indeed, referring to literature on SMEs' innovation processes, studies document that these organizations rely extensively on external stakeholders for new knowledge to overcome their knowledge limitations, develop and enhance their capabilities, envision arising opportunities and challenges, and be better prepared for developing innovation solutions (Hafeez et al., 2025; Shahzad et al., 2025; Tiberius et al., 2021). Knowledge exploration and exploitation processes are key to SMEs' innovations. Recent studies have explored the linkage between SMEs' knowledge depth and breadth for Industry 4.0 adoption (Haug et al., 2023; Ricci et al., 2021). Despite the early efforts in understanding the SMEs' technological knowledge acquisition and its significance for technology implementation, there remains a strong need for further research to explore the interplay between explorative approaches and exploitative mechanisms for technological knowledge exploration and exploitation (Orlandi, 2016).

Reflecting upon the existing literature reviews, we acknowledge that studies have highlighted the antecedents and contributing factors of digital transformation in SMEs. For instance, Anshari et al. (2022) highlighted that digital ecosystem readiness and local government support are essential enablers for the adoption of Industry 4.0 technologies among Indonesian SMEs. Slimane et al. (2022) delineate that internal organizational factors such as digital infrastructures, processes, digital managers, and management orientation to organizational change are key enablers in the digital transformation of SMEs. Marino-Romero et al. (2024) explain the interconnection between organizational digital orientation, agility to respond to external disruptions, and digital transformation management. Ramdani et al. (2022) presented a list of environmental antecedents, internal organizational factors, and capabilities to develop digital innovations. Mele et al. (2024) review emphasized the significance of SMEs' internal dynamic capabilities in sensing, seizing, and adapting to digital opportunities and external technological knowledge for effective digital transformation.

The referred studies highlight the importance of organizational and individual-level capabilities to contextualize the externally available new technological knowledge. To the best of our knowledge, no prior research has explicitly focused on a systematic synthesis of literature that utilizes a KBV framework that outlines the complex relationships and interplay between SMEs' technological knowledge explorative approaches and exploitative mechanisms for digital transformation. The need for our research is further justified by the call for future research by Ramdani et al. (2022) and Haug et al. (2023) to explore mechanisms and approaches that support SMEs in their quest for the implementation of emerging technologies for developing digital innovations and enabling digital transformation. Table 1 summarizes existing literature reviews and their limitations in the context of knowledge management for digital transformation.

In this context, a systematic synthesis of existing literature can contribute significantly to the academic community's understanding by providing a comprehensive framework explaining the interplay between SMEs' knowledge explorative approaches and internal mechanisms to internalize and utilize the acquired knowledge for digital transformation. Studying the external knowledge exploration and exploitation process is highly interesting, as the field is challenging to analyze and SMEs are less transparent; thus, a systematic literature review helps find new insights. Our findings suggest that SME have two distinct collaborative models: (I) core value chain and network actors' collaborations, and (II) ecosystem and innovation platform-based collaborations. Findings indicate that the nature of collaborations, relationships among actors, exchange of knowledge and resources, and dependencies among actors vary between the two collaborative models, affecting SMEs' capacity to acquire, internalize, and utilize technological knowledge for their digital transformation. Our study contribution lies in presenting two collaborative models of SMEs' technological knowledge exploration and exploitation through the lens of a KBV. Findings also suggest that external actors such as customers, suppliers, intermediary organizations, and competitors play specific roles in SMEs' digital transformation. Our study answers the following three overarching research questions.

R.Q-1: How do SMEs explore and acquire external technological knowledge?

R.Q-2: How do SMEs internalize and utilize the externally explored technological knowledge for digital transformation?

R.Q-3: What are the future research guidelines based on this literature review?

The remaining body of the paper is structured into five sections: review planning and methodology, findings, discussion, conclusions, limitations, and future research directions.

Review planning and methodology

A *systematic literature review* (SLR) is "a review of a formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies included in the review" (Moher et al., 2009, p. 264). This definition asserts that answering a research question through SLR must be supported by systematic and rigorous methods to identify, select, and evaluate the relevant literature. The SLR is viewed as an appropriate approach to identify key findings in the literature, delineate relationships among different factors, conduct an in-depth evaluation of the literature on the topic, and offer concrete future research directions (Paul & Benito, 2018; Snyder, 2019; Webster & Watson, 2002). Reflecting on our research objectives, which aim to explore the interplay between SMEs' knowledge of exploratory and exploitative approaches for implementing technologies to develop technological solutions, we found the SLR to be the most relevant research approach to help us conduct a rigorous, systematic appraisal of the extant literature to delineate complex relationships embedded in knowledge exploration and exploitation for technological advancements. Paul and Benito (2018), Webster and Watson (2002), and Snyder (2019) suggested four phases for conducting SLRs: designing, conducting, analyzing, structuring & reporting. We followed this four-step procedure to conduct this SLR. Figure 1 presents the phases and components of each phase considered while conducting an SLR.

Designing and conducting the review

The first step in the design phase is to identify the need and define the SLR's contribution. SLRs are well-structured approaches to summarizing literature and gaining a deep understanding of the phenomena under

Table 1
Overview of existing literature review on digital transformation in SMEs.

Authors	Study Focus	Key Themes	Limitations & Research Gap
Anshari et al. (2022)	Open innovation strategies for SMEs' digital transformation	- The positive link between digital ecosystem readiness for I4.0 adoption - Relevance of Knowledge management for open innovation implementation - Government as a protector of market regulations	- Lack of analysis of technological knowledge exploration and exploitation - Limited to the Indonesian context
Slimane et al. (2022)	Integrated framework and managerial dimensions for a digital transformation strategy	- Digital infrastructure and digital manager relevance for digital transformation - Reconfiguration of organizational and managerial mechanisms - Top Management is responsible for digital change management	- Shallow analysis of the relevance of knowledge management for DT
Ghobakhloo et al. (2022)	Identify influencing factors for I4.0 adoption	- Technological determinants - Organizational determinants - Environmental determinants - I4.0 adoption roadmap	- Despite explaining environmental determinants, research lacks an in-depth evaluation of SMEs' various interactions and their relevance for adopting I4.0 technologies.
Ramdani et al. (2022)	Synthesis of research on digital innovations	Overview of: - Digital technologies - Theories for Digital Innovations - Contextual and organizational factors for digital innovations	- Lacks in-depth analysis to show how SMEs interact with external actors, and what their role is in digital transformation
Mele et al. (2024)	Knowledge-based dynamic capabilities for digital transformation	- Micro-foundation of dynamic capabilities - Dynamic capabilities for value creation - Dynamic capabilities for - Digital transition - Dynamic capabilities for "data-driven organizations - Dynamic capabilities for digital transformation in SMEs and family firms	- Lack of details on how SMEs leverage their external networks to acquire relevant knowledge and what kind of support they receive from external actors - Missing details on the intricate process of knowledge exploration to exploitation for digital transformation.
Marino-Romero et al. (2024)	Orientation of digital transformation in the management and organizational processes	- Digital transformation promotes agility in organizational processes. - Development of digital capabilities - Strategies for scaling up digital technologies	- Lack of analytical depth in leveraging dynamic knowledge acquisition and internalization capabilities. - Provide a bibliometric overview of the studies, with a missing systematic literature analysis.

investigation. During the planning phase, it is inevitable for researchers to review extant research critically to ensure that a concrete need exists to conduct an SLR that will help enhance understanding of the relevant academic community, practitioners, or policymakers significantly (Snyder, 2019). Thus, justifying the need for an SLR stems from the limitations of extant research regarding inconclusive evidence, contradictory findings from extant research, and a lack of a framework for academics and practitioners to guide them on specific phenomena. In this context of current research, details on justifications and rationale for conducting this SLR are provided in the introduction section, in which we explicitly explain the limitations of extant research, linking it to a clear literature gap and highlighting the need for further research on the knowledge exploration and exploitation process in SMEs for digital transformation. Furthermore, we identified two models based on different collaborative mechanisms and exploitative strategies that SMEs utilize for knowledge exploration and exploitation. Such contributions are much-needed because the frameworks, on one hand, contribute to the literature on information systems and business management, and on the other hand, provide practical implications for SME management in selecting and prioritizing different collaborative mechanisms, tailored to their innovation goals and internal capabilities. We aimed to achieve these objectives by answering the three research questions (please see the introduction section).

The relevant literature search began by defining the conceptual boundaries of key concepts examined in the research. The primary constructs in our research are knowledge exploration, exploitation for digitalization, and digital transformation. *The knowledge exploration process has been described as SMEs' new knowledge search, exchange, creation, and acquisition through different collaborations. Knowledge exploitation is the internalization and utilization of acquired knowledge for digital transformation.* The definition of *digital transformation* in this study was adopted from Soluk and Kammerlander (2021): "SMEs' progression from converting firm processes to digital forms, integrating digital technologies into products and services, and transforming entire business models".

As for a definition of *SMEs*, we found varying definitions based on number of employees and turnover. For example, the European Union (2015) classifies business organizations with 1–250 employees as SMEs, while in the United States, the Small Business Administration classifies organizations with less than 500 employees as SMEs. The same goes for the Middle East and Far East, where SMEs are organizations with fewer than 500 employees. *Therefore, it is difficult to find a universal definition of SMEs, so we used 500 employees as a cut-off point for SMEs to widen the study's scope.*

Defining the conceptual boundaries is a systematic step in developing the review protocol, as the process helps researchers identify limits and map core concepts of the research. Researchers have contended that reviewing protocol documentation is critical to maintaining conducted studies' validity and reliability (Torracco, 2016). The review protocol helps researchers map out key concepts in the review and limits researcher bias during different stages of conducting the SLR (Ali et al.,

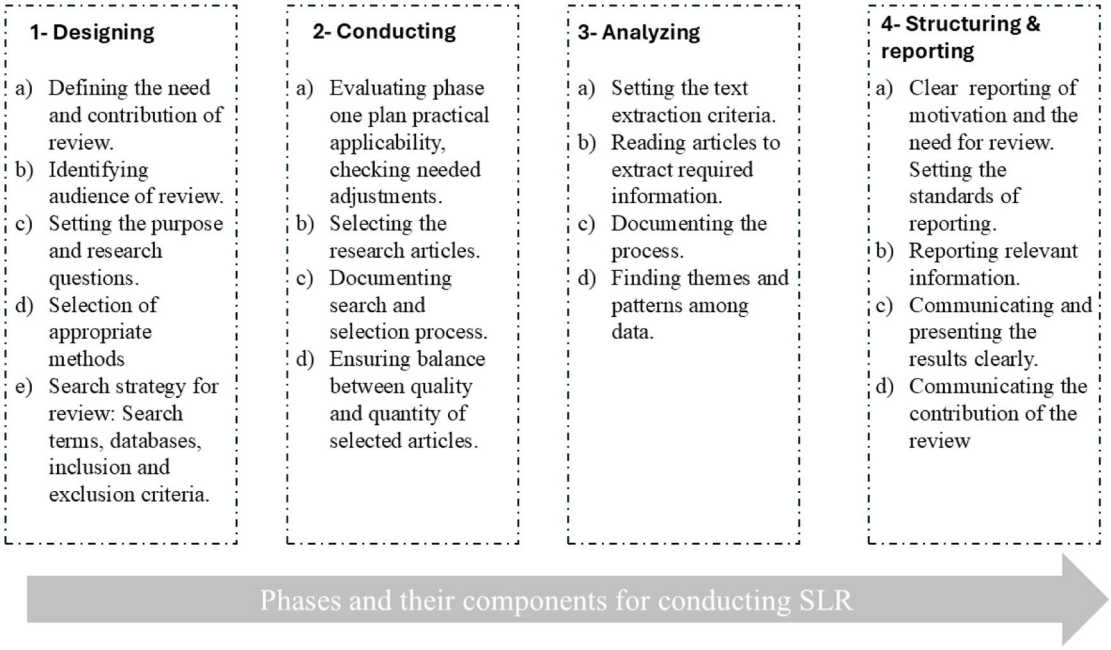

Fig. 1. Phases of conducting a SLR.

2023). In our research, we focused on concepts related to knowledge exploration and its exploitation in SMEs' digitalization and digital transformation (Figure 2 presents the conceptual framework for keyword selection). The knowledge exploration process includes different types of SME collaboration with external actors, such as supply chain collaborations, interorganizational collaborations, university-industry collaborations, open innovation, network collaborations, ecosystem collaborations, and, most recently, platform-based collaborations. The knowledge exploitation process comprises two stages: first, knowledge internalization, and second, its utilization for different outcomes. Our research focuses on exploring internal factors, capabilities, and organizational strategies that support knowledge internalization and the successful utilization of technological solutions. Thus, based on the review protocol, we started searching for relevant concepts in top journals in information systems management, business, and economics due to the topic's multidisciplinary nature. After examining 20 research papers on the topic, we compiled an initial list of keyword searches that we conducted in the Scopus and Web of Science databases. Webster and Watson (2002) recommend this technique, as it helps researchers map out the topic and find the most relevant key terms from the leading body of literature on the given topic.

During the next step, we consulted one external expert in the field on this keyword combination based on Ali et al. (2023) and Slimane et al. (2022). Using these experts' recommendations, we updated the search query and conducted another literature search. Selecting search terms is an ongoing process, so two research team members conducted separate search queries with lists of search terms. During the final step, both researchers compiled a final list of search terms and conducted literature

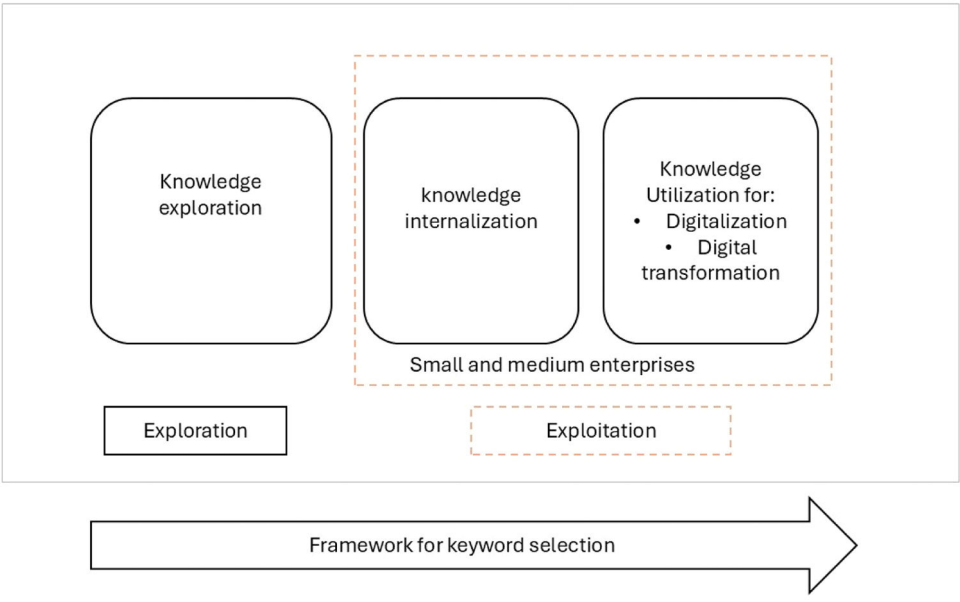

Fig. 2. The conceptual framework for keyword selection.

searches in the Scopus and Web of Science databases. Other researchers have argued that selecting a database for a literature search is central to reaching out to relevant research, particularly while conducting review studies (Snyder, 2019; Webster & Watson, 2002). In this regard, one researcher explained that Scopus is a comprehensive database that contains the most significant number of indexed journals (Snyder, 2019). However, other researchers suggested that authors should include at least two databases to broaden coverage of included data (Ramdani et al., 2022; Pfister & Lehmann, 2023). Therefore, we chose Scopus and Web of Science for the literature search to ensure a broader range of data for our review and reduce the risk of omitting important research. The final keyword combination and query are provided in Table 2.

During the initial search, we found 848 relevant research papers (485 in Scopus; 363 in Web of Science). Aside from searching for literature on databases, we also backtracked citations from the resulting papers and supplemented data through a manual Google Scholar search. We searched for relevant literature in top-tier and leading business management and information systems journals. Webster and Watson (2002) suggested this search technique, which is beneficial in identifying significant contributions in the research field. The manual search was conducted on Association of Business Schools (ABS)-ranked (Levels 2 and 2+) journals' homepages. Altogether, 50 articles were found in a manual search on Google Scholar and from backtracking citations. However, we were left with 752 peer-reviewed empirical papers after duplicates were removed. We narrowed the review scope by defining inclusion and exclusion criteria. Due to the topic's interdisciplinary nature, we searched for research papers across different fields of study, i.e., computer science, operations research, decision science, business, and management. A similar approach has been proven beneficial in Robey et al. (2000). We included only papers published in English during the 2004–2024 period. We focused only on research papers published in peer-reviewed journals, excluding conference proceedings and book chapters. This is important because most conference proceedings and book chapters are published without critical evaluations (Sivarajah et al., 2017). Furthermore, we excluded conceptual, editorial, and literature review papers. We focused only on papers with practical research designs because we wanted to focus on backing our findings with empirical evidence. Finally, we only chose papers published in ABS-ranked journals (Levels 2, 3, 4, and 4*) for two reasons: First, we aimed to build this study's findings based on leading work in the field. Second, such a criterion helped keep the sample size manageable without omitting relevant work (Calabrò et al., 2019). After applying ABS criteria, backtracking citations, and manual searches, we had a total of 364 papers that were selected for further criteria checks. During the final step, we checked papers for their relevance to our research goals, i.e., the paper must discuss knowledge exploration or exploitation processes pertinent to technological implementation, upgradation, technological innovations, technological utilization, technological development, technological transfer, or development of technological solutions (products, services, or business models). Table 3 documents the criteria checklist:

After applying the quality and eligibility criteria, 108 studies qualified as the study's final sample. Figure 3 presents a PRISMA flow diagram explaining the identification, screening, eligibility, and selection processes for research papers included in the study's final sample.

Conducting the analyses

The data analysis was conducted systematically in a recursive process utilizing NVivo software, VOSviewer software, and manual reading of papers. We conducted keyword and author co-occurrence network mapping during the first phase using VOSviewer, which helped us map the interrelated cluster of studies and find the most influential authors in the research area (Fig.s are provided in the appendix). We then manually read the most cited relevant papers comprising 10% of the total sample. This process enabled us to increase our understanding of concepts, themes, and theoretical frameworks utilized in the context of the researched topic. After manually reading the full papers, we compiled an initial list of factors for the data extraction form. During the next stage, we used NVivo software to conduct automatic code queries on all papers. Such a query is mentioned as a pre-coding process (Bandara et al.,

Table 3
Eligibility criteria.

Inclusion criteria	Exclusion criteria
ABS Rankings of Journal: 2, 3, 4, & 4*	ABS Rankings of the journal: below 2
Publication Type: Peer-reviewed research articles	Publication Type: Book chapters, conference proceedings
Years: 2004–2024	Years: Less than 20 years old & articles in the press
Methodology: Qualitative, quantitative, mixed methods	Methodology: Review articles, editorial, and conceptual papers
Content: Articles that primarily focus on technology adoption, implementation, and utilization, and the role of knowledge or collaborations	Content: Articles that mention technology outcomes only; articles that mention technology utilization but are not focused on knowledge and collaborations; articles that focus only on internal organizational factors for technology adoption and utilization
Language: English	Language: Other than English
Subject: Business and Economics, Computer Science, Information Systems, Decision Science, Engineering Management	Subject: Other than mentioned in the inclusion criteria

Table 2
Final keywords combination and query.

Final query 22.04.2024:

Scopus:

TITLE-ABS-KEY (("Digital inno*" OR "Digital Tech*" OR "Digital*" OR "ICT" OR "technolog*" OR "Industry 4.0" OR "Industry 5.0" OR "smart technolog*" OR "digital integration" OR "business intelligence" OR "Big data" OR "data capabilit*") AND ("knowledge exchange" OR "knowledge search" OR "knowledge sharing" OR "knowledge exploration" OR "knowledge acquisition" OR "knowledge receiving" OR "knowledge exploitation" OR "knowledge utilization" OR "knowledge integration" OR "ecosystem collaborations" OR "open innovation" OR "business ecosystem" OR "knowledge ecosystem" OR "innovation ecosystem" OR "entrepreneurial ecosystem" OR "technological ecosystem" OR "digital ecosystem" OR "service ecosystem" OR "knowledge network*" OR "business network*" OR "co-creat*" OR "co creat*" OR "collaborative innovation" OR "co-innovat*" OR "co innovat*") AND ("SME*" OR "Small medium enterpris*")) AND PUBYEAR > 2003 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))

Web of Science:

("Digital inno*" OR "Digital Tech*" OR "Digital*" OR "ICT" OR "technolog*" OR "Industry 4.0" OR "Industry 5.0" OR "smart technolog*" OR "digital integration" OR "business intelligence" OR "Big data" OR "data capabilit*") AND ("knowledge exchange" OR "knowledge search" OR "knowledge sharing" OR "knowledge exploration" OR "knowledge acquisition" OR "knowledge receiving" OR "knowledge exploitation" OR "knowledge utilization" OR "knowledge integration" OR "ecosystem collaborations" OR "open innovation" OR "business ecosystem" OR "knowledge ecosystem" OR "innovation ecosystem" OR "entrepreneurial ecosystem" OR "technological ecosystem" OR "digital ecosystem" OR "service ecosystem" OR "knowledge network*" OR "business network*" OR "co-creat*" OR "co creat*" OR "collaborative innovation" OR "co-innovat*" OR "co innovat*") AND ("SME*" OR "Small medium enterpris*") (All Fields) and Early Access or Review Article or Proceeding Paper or Retracted Publication (Exclude – Document Types) and Editorial Material or Book Review or Correction or Meeting Abstract (Exclude – Document Types) and Management or Business or Computer Science Information Systems or Engineering Manufacturing or Multidisciplinary Sciences (Web of Science Categories) and English (Languages)

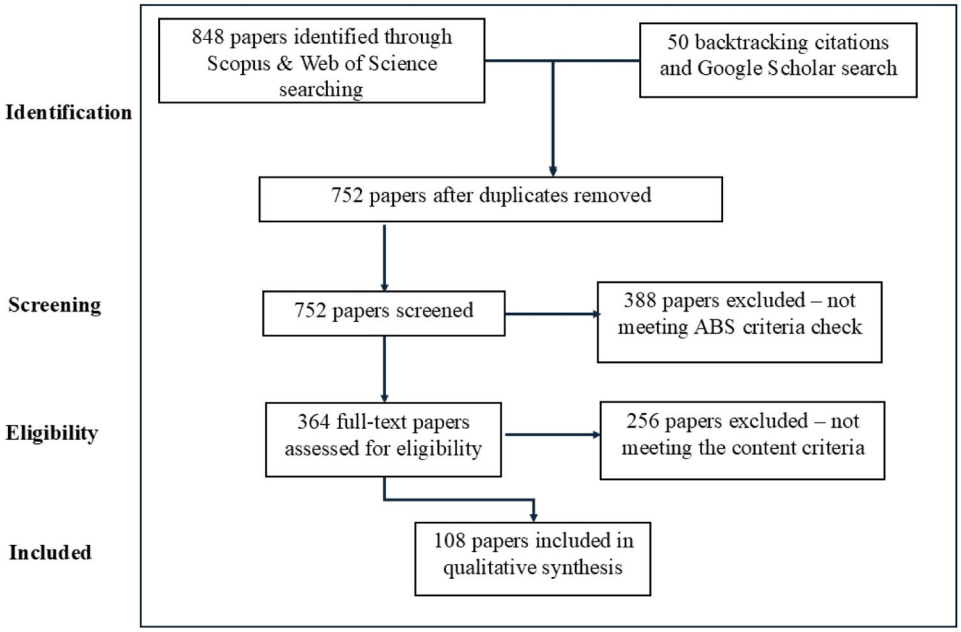

Fig. 3. PRISMA flow diagram.

2011) that helps understand the most important codes, keywords, and concepts appearing frequently in the given papers. Utilizing NVivo during the review-writing process can reduce the possibility of human error (Chavez et al., 2022), as its features enable researchers to capture, code, retrieve, and analyze literature in a single repository (Bandara et al., 2011). Moreover, the pre-coding process helped us form a broader picture of the retrieved literature and identify dominant codes in our sample papers. By creating a matrix, NVivo also helped us understand co-occurrence between the most frequent terms. This process supplemented compilation of data extraction forms by providing an overview of key emerging terms. Moreover, by forming a word cloud in NVivo, we found that collaboration, knowledge, innovation, technological, and capabilities were the most frequently used terms in the selected papers. Such results validate selected papers' suitability to answer the research questions. Figure 4 presents the word cloud.

Based on the following steps, we compiled a list of codes for the data extract form and conducted a manual search for the final coding of the results. Following these steps ensured that the researcher's biases were mitigated during the selection and analytical process. We compiled an objective list of codes to help us answer the research questions. Figure 5 presents an overview of the steps followed during the data analysis stages of the SLR.

Structure and reporting

Description of data

The annual distribution of published articles indicates that the importance of knowledge exploration and collaborations for digital solutions development has increased over the past decade. As Figure 6 indicates, before 2010, only five research papers on this topic existed, but starting in 2011, an increase in publications can be observed, with the highest number of publications, 18, in 2023, followed by 17 in 2022. Thus, it is evident that there has been a growing interest among researchers concerning the present study's topic. While the body of literature on this topic has been growing, we observed a dip in 2021, and based on our understanding and extant research, during the COVID-19 pandemic, researchers and companies' focus shifted toward attaining short-term resilience, a strategy known as serving the shocks of disruption. This phenomenon hindered organizations and researchers' investments in resources to explore, adopt, and develop new

Fig. 4. Word cloud for the most frequent terms.

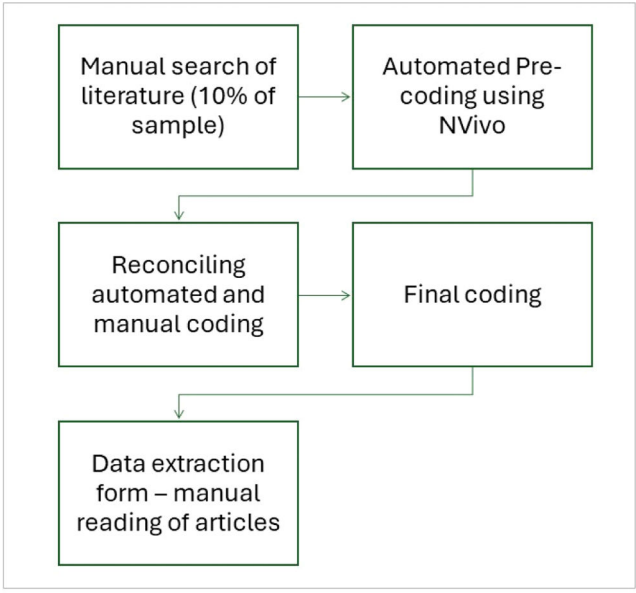

Fig. 5. Steps followed during the data analysis phase.

technologies to improve existing processes. The pandemic compelled organizations to utilize technology in their internal organizational practices, such as human resource management (HRM) and communication among teams and employees through online meeting tools (e.g., MS Teams, Zoom, and Skype). Our literature search did not include papers that examined technological development and utilization in the very specific context of communication and HRM practices. Our rationale is that the scope of our research was limited to the collaborative aspect of digital transformation in SMEs, leading to omission of studies that focused merely on organizational internal technology adoption in HRM management and health and biotech sector companies.

Moreover, a descriptive data analysis reveals that *Technological Forecasting and Social Change* was the most popular journal among researchers, publishing 11 papers, followed by *Technology Analysis and Strategic Management* and *Technovation*, with eight papers each. Similarly, the *Journal of Business Research* and *Production Planning and Control* published six papers each. Figure 7 provides an overview of journals with the highest frequency of published papers on this topic, demonstrating the multi-disciplinary nature of conducted research that expands across journals from different domains, e.g., strategic management, information systems research, innovation management, and engineering management.

Findings

The data analysis process began with a review of the papers listed in NVivo, in which we compiled and agreed on the list of codes. A content analysis was conducted, and researchers read full papers while analyzing the problem statement, literature gap covered, research question(s), objectives, theories, conceptual framework, methodology, results, and each paper's contributions. Based on the content analysis, we answered our study research questions:

R.Q-1: How do SMEs explore and acquire external technological knowledge?

R.Q-2: How do SMEs internalize and utilize externally explored technological knowledge for digital transformation?

R.Q-3: What are the future research guidelines based on the literature review?

By following the aforementioned research methods, we conducted a detailed analysis of the relevant literature to answer the research questions pertinent to SMEs' external knowledge exploration. This rigorous process ensured that themes and results emerged with acceptable reliability and validity to achieve the study's objectives. The findings from the literature indicate that in the external business environment, SMEs collaborate with different actors through various mechanisms; therefore, exploring each actor's role and contribution further is indispensable for understanding SMEs' knowledge exploration process. We also found that these actors collaborate through different mechanisms, which we categorized into (I) core value and network actors' collaborations and (II) ecosystem and innovation platform collaborations.

Actors' roles and activities in SMEs' digital transformation journey

Customers, suppliers, and competitors

Our in-depth exploration of the literature recognized the important role played by customers and suppliers during different phases of digital transformation within SMEs. Review results indicate that customers can be determinants of and catalysts for digital transformation within SMEs. Key players compel SMEs to adopt technological solutions to maintain

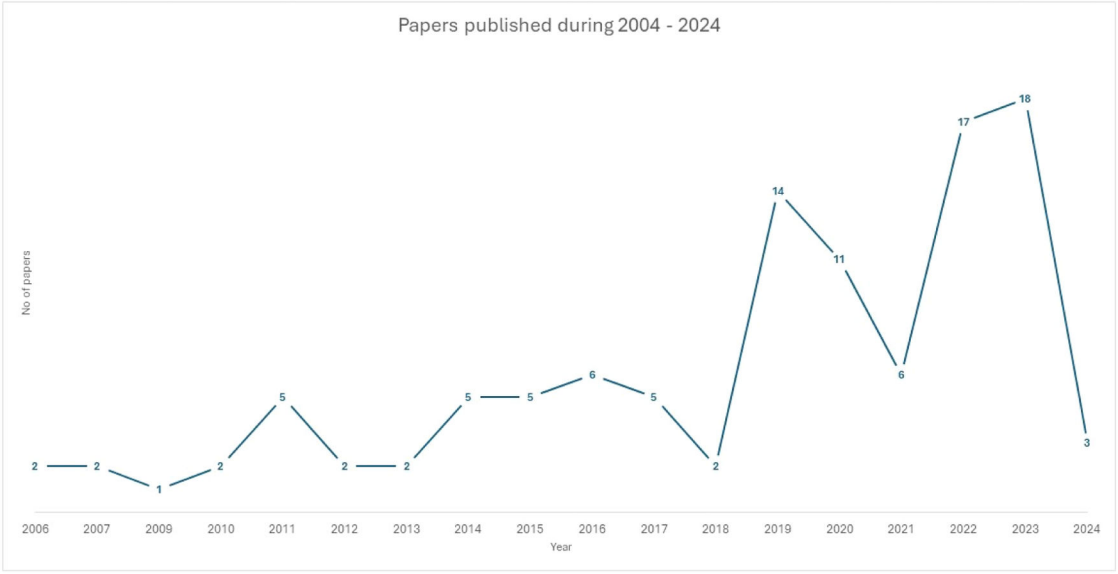

Fig. 6. Year's distribution: Literature search conducted in April 2024.

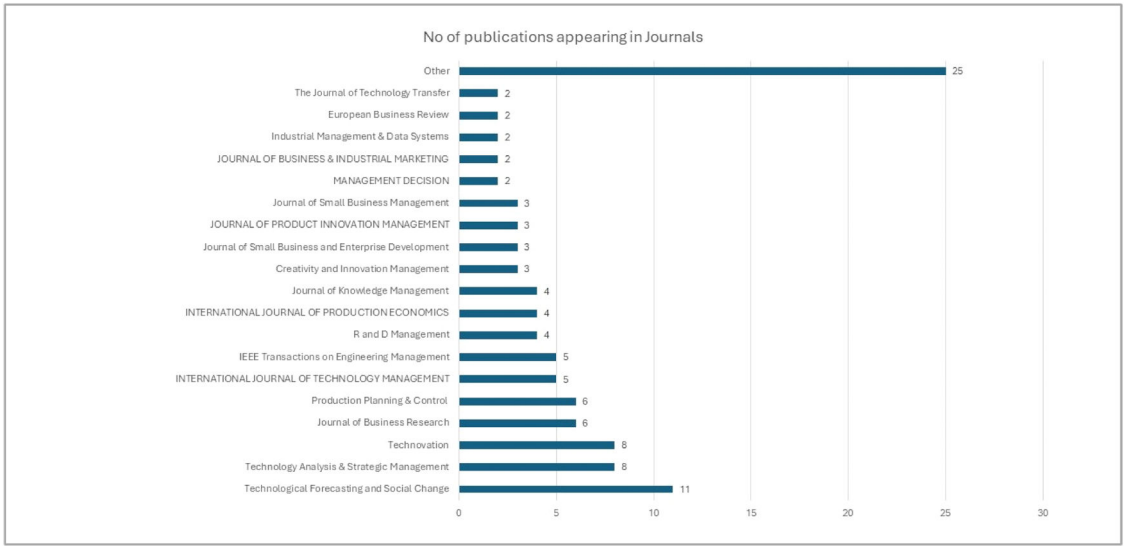

Fig. 7. Frequency of papers published in journals.

partnerships; however, catalysts motivate and assist SMEs in implementing technological solutions to realize additional benefits and seize opportunities that digital technologies provide. Both determinants and catalysts play essential roles in adoption, implementation, and utilization of digital technologies. Customers' determinant role drives supplier SMEs to explore and adopt technological solutions, leading management to synchronize its digital systems with the broader supply chain. Customer demands increase SMEs' technological, managerial, and operational readiness for implementing I4.0 technologies (Gutierrez et al., 2015; Stentoft et al., 2021). Estensoro et al. (2022) explained that technology non-implementors mainly lacked customers' push for technology adoption. Customer demand for technology implementation is one of the major triggers for digital transformation within SMEs (Khin & Kee, 2022), while availability of financial support and funding acts as an explanatory factor for the testing and trial phases of new technology implementation (Ballestar et al., 2020). Even though customer-supplier relationships' determinant nature acts as the trigger for digital transformation, technology implementation in such a context has been met with certain challenges for SMEs, including limited financial resources, lack of organizational innovation and technology implementation strategies (Hansen et al., 2024; Soluk & Kammerlander, 2021), lack of organizational readiness, and lack of needed support from customers (Salvini et al., 2022). Therefore, the customer-supplier relationship's determinant nature has not been discussed widely in the digital transformation literature. Instead, most researchers have focused on the catalyst's nature of customer-supplier relationships for digital transformation in SMEs.

The catalyst nature of relationships entices customers and suppliers to work closely together and collaborate in implementing and utilizing digital technologies to seize various opportunities arising in their business environments. Notably, digital transformation through such collaborations is not limited to grasping new opportunities. Motivation for collaborations can vary, from increasing supply chain performance (Scuotto et al., 2017) and organizational performance (Radicic et al., 2019), to improving existing organizational processes' effectiveness and efficiency (Ricci et al., 2021). Proximity plays a crucial role in such customer-supplier relations, which can be divided into three types: spatial; technological; and social proximity. Spatial proximity refers to geographical closeness of collaborating actors' locations. Technological proximity encompasses the level of technological knowledge symmetry, alignment between existing technological systems, and organizational technological readiness between customers and suppliers (Benitez et al., 2020; Hwang, 2023; Marullo et al., 2024). Social proximity pertains to the understanding and strengths of social relationships between customers and suppliers (Benitez et al., 2020).

Customer and supplier collaborations occur at various phases and levels, directly impacting SMEs' journey toward digital transformation. Estensoro et al. (2022) explained that SMEs during the early stages of digital transformation collaborate with their customers to enhance their technological awareness through discussions. During the second stage, SMEs develop technological awareness and aim to create concrete solutions through collaborations. In this context, they partner with broader networks of customers, which provide them with financial resources and focused workshops on implementing and utilizing new technologies in their organizational processes (Chipika & Wilson, 2006; Ricci et al., 2021). This allows SMEs to enhance technological learning, improve digital readiness, and test various technological solutions through network collaborations. This stage also includes cocreating technological solutions with a network of customers, thereby advancing SMEs' internal technological capabilities for technology adoption and implementation (Benitez et al., 2020; Eikebrokk et al., 2020; Mawson & Brown, 2017; Zhang, 2024). The third stage represents a more sophisticated approach, in which SMEs collaborate with their customers and other participants within ecosystem collaborations. In such collaborations, the facilitating or orchestrating actor establishes the collaboration target, generally with a broader agenda than merely focusing on SME technology development (Li et al., 2023; Sassanelli & Terzi, 2022). Successful collaboration with customers in ecosystem and platform collaborations is evident in the highest technological and relational proximity levels between customers and suppliers, as these collaborations evolve based on their targets. Such proximity is driven by economic, technological, and market factors (Kahle et al., 2020). While the early phases of ecosystem collaborations may be driven by economic factors, the evolutionary perspective suggests that technological and market drivers mutually influence one another regarding digital transformation and the use of technologies to meet current and future market demands. A few studies have analyzed coopetition among SMEs for technological purposes explicitly, and only these studies examined competitors' collaborations, explaining that competitors and organizations with similar business models can stimulate bricolage. SMEs need to be outward-facing and receptive to external stimuli (Haug et al., 2023; AL-Khatib et al., 2024; Hervas-Oliver et al., 2021; Khurana et al., 2022; Radicic et al., 2019).

Government organizations

The literature evaluation indicated that governments play an

important role in SMEs' digital transformation. In this regard, researchers have examined federal, regional, and local governments' roles in SMEs' digital transformation. Government support can be divided into two main categories: financial assistance and policymaking. Although these two categories are distinct, they are interrelated, as government policymaking may involve various aspects of financial assistance, such as creating policies to prioritize funding areas for developmental projects to enhance SMEs' digital transformation. Similarly, government policymakers can develop strategies to offer tax benefits and subsidies to SMEs aiming to collaborate, implement new technologies, and support organizations that strive to enable digital transformation among SMEs:

- Financial support directly to SMEs: for technology upgrades; tax benefits for collaborative innovation; subsidies for engaging in collaborations; and for trying out new solutions (Chakravarty, 2022; Hwang, 2023; Khin & Hung Kee, 2022).
- Regional funds to support development of cocreation-based, high-risk projects with universities, startups, and other technology organizations to understand technology implementation and commercialization of new technologies: grants and funding for testing new technologies; funding for collaborative learning-based projects; IPR-based licensing; and training entrepreneurs and collaborative innovation by supporting technological capability development (Bharati & Chaudhury, 2010; Doh & Kim, 2014; Garrigos et al., 2011).
- Financial support for competency centers: federal government support through establishment of competence centers; fostering the nexus/interconnection of multiple actors to identify opportunities for basic technological upgrading; exploring new technology-based business models; and developing smart products (Clegg et al., 2017; Ho et al., 2016; Ietto et al., 2022; Kolade et al., 2019; Prodi et al., 2022).
- Other financial assistance: grants and funds; tax benefits; subsidies; loans from government-affiliated financial institutions; and technological development assistance funds (Chung & Kim, 2023; Mahdiraji et al., 2023).
- National-level strategies and policies: a) Incentives for testbed projects that can serve as reference models for specific sectors; b) tax incentives and funds for acquisition of smart equipment and import of components; and c) data security regulations. The government can incentivize high-risk technological projects (Gupta & Barua, 2016; Kahle et al., 2020; Park et al., 2022).

Intermediary organizations

Different types of intermediary organizations play specific roles in enabling collaboration and technological knowledge transfer for SMEs' digital transformation. In their basic function, all intermediaries act as matchmakers and knowledge brokers in transferring technological knowledge among business and nonbusiness actors. However, knowledge and technology transfer's success depends on the quality of services and facilitation activities that intermediaries offer (Gao et al., 2023). Intermediaries provide advanced services, advice, and assistance to SMEs in their innovative processes. They also engage in boundary-spanning activities aimed at connecting different actors in collaborative projects, such as linking universities and companies for collaborative research projects, connecting companies for value cocreation-based projects, and facilitating a joint search for new knowledge (Comacchio et al., 2012; Kahle et al., 2020). SMEs collaborate with cooperative associations to access public financial support for executing joint R&D projects (Fukugawa, 2018). Intermediary organizations also facilitate SMEs' innovation processes by offering expert opinions on strategic decision-making regarding technology investments and beyond. Moreover, they play crucial roles in disseminating knowledge, transferring technology, and providing business support, thereby extending their role from knowledge brokers to innovation facilitators. In this capacity, they dynamically contribute to the innovation process, ensuring access to necessary resources from the initial idea to commercialization of the final product (Battistella et al., 2023; Bojica et al., 2018; Tremblay et al., 2015). SMEs' collaboration with intermediary organizations is dynamic and complementary, enabling them to benefit from the diverse services and expertise offered by different intermediary organizations. Knowledge brokering and innovation facilitation roles are performed by traditional intermediary organizations, such as technology transfer centers (TTCs), cooperative associations, consultants and technology providers, knowledge institutions (research and technology institutes, and universities), and market intermediary organizations.

However, a relatively new type of intermediary organization recently has emerged—the *systematic intermediary*—defined as a "network of intermediary organizations incorporating multiple and heterogeneous competencies to facilitate and shape the transition of a complex sociotechnical system" (Prodi et al., 2022). Systematic intermediaries engage in unique activities that enable SMEs' digital transformation, coordinating and regulating collaborations with collaboration orchestrators and advocating for joint production of legislation and self-regulation (Berkowitz & Souchaud, 2024). Intermediaries within systematic intermediaries support each other in capacity-building through incubations, spin-offs, integrations, mergers, and direct transfer of knowledge and expertise (Ietto et al., 2022; Berkowitz & Souchaud, 2024). Moreover, systematic intermediaries also are involved in knowledge integration and sharing among cross-domain actors, thereby creating a knowledge-based supply chain system (Li et al., 2023). By performing these services and activities, systematic intermediaries facilitate sociotechnical transitions and serve as capacity-building actors for SMEs. This includes offering tailored digital solutions to meet the needs and challenges of SMEs across various industries, scales, and processes (Ferneley & Bell, 2006). Notably, knowledge sharing and integration are critical to collaborations' success and in developing digital solutions for SMEs. Thus, systematic intermediaries act as capacity-building organizations, enabling SMEs to absorb newly generated knowledge into the digital transformation of their operations, offerings, and business models. Table 4 details actors' roles in supporting SMEs in technological knowledge exploration and exploitation.

SMEs' collaborative mechanisms for technological knowledge exploration and exploitation

The literature findings suggest that SMEs collaborate with external actors, including interorganizational collaborations, network actors, core value chain actors, and ecosystem and platform-based collaborations. By distilling commonalities and unique qualities from these different collaboration types further, we found that SMEs' collaborations can be categorized into two distinct groups: I) core value and network actors' collaborations, and II) ecosystem and innovation platform collaborations. Below, we discuss details on SMEs' collaborations in these two distinct models.

(I) Core value and network actors' collaborations

Results from the review suggest that collaborations with core value chain actors help SMEs search for new digital opportunities by enhancing their leadership vision on new technologies, increasing their industry-specific technological knowledge, and enabling them to grasp identified opportunities (Ricci et al., 2021; Scouto et al., 2017). Close relational proximity and long-term collaborations enable SMEs to access in-depth knowledge about emerging technological opportunities and configurations required to implement such technologies (Lepore et al., 2023; Tranekjer & Knudsen, 2012), particularly in product design and manufacturing operations, and product diversification (Chipika & Wilson, 2006). Similarly, these actors also help SMEs manage collaborations that are pertinent to gaining technological and organizational capabilities (Hwang, 2023), thereby fostering adoption of I4.0 technologies (Stentoft et al., 2021) and boosting their operational readiness for I4.0

Table 4
Actors and their roles.

Actors	Types	Role of actors	Relevant papers
Customers	Determinants	• Encourage suppliers to upgrade their technology and integrate new technologies. • Offer non-financial support for operational, managerial, and technological readiness. • Foster closed-loop collaboration for supply chain-related technologies.	Estensoro et al. (2022); Del Giudice et al. (2021); Radicic et al. (2019); Soluk & Kammerlander (2021); Chipika & Wilson (2006); Stentoft et al. (2021); Mawson & Brown (2017); Bharati & Chaudhury (2010); Benitez et al. (2020); Brown & Mason (2014); Zhang (2024); Kahle et al. (2020); Isensee et al. (2020); Wadhwa et al. (2017); Saunila et al. (2019)
	Catalysts	• Open a collaborative approach for broader technology development, testing, and trialing new digital technologies. Identify opportunities related to discovering digital solutions. • Maintain close spatial, technological, and social proximity to enhance the effectiveness and efficiency of technology for operations and processes, new product development, and alignment with emerging digital business models. • Co-develop digital solutions. • Support acquiring financial and human resources for digital transformation in collaboration with other stakeholders. • Develop technological capabilities.	
Govt organizations	Federal Govt	• National technology policy • Tax and subsidies for the development of new technology solutions • Development of competency centers • Incentives for testbed projects • Data security regulation	Albors-Garrigós et al. (2011); Bharati & Chaudhury (2010); Brown & Mason (2014); Chakravarty (2022); Chung & Kim (2023); Doh & Kim (2014); Fukugawa (2018); Gupta & Barua (2016); Hwang (2023); Ietto et al. (2022); Kahle et al. (2020); Khin & Hung (2022); Kolade et al. (2019); Mahdiraji et al. (2023); Park et al. (2022); Prodi et al. (2022); Wynarczyk (2013).
	Regional Govt	• Regional funds for the co-creation of high-risk technology projects • Grants for testing and trial of new technologies • Training of top management for technology adoption and utilization	
	Local Govt organizations	• Technology development assistance funds • Direct grants and funds to local SMEs • Lobbying for favorable national policies	
Intermediary organizations	Cooperative Associations Market intermediary organizations Universities Research Institutes	*Knowledge brokers:* • Matchmakers • Advice and assistance in the innovation process • Boundary spanners • Access public funds for collaboration to execute	Berkowitz & Souchaud (2024); Bharati & Chaudhury (2010); Comacchio et al. (2012); Comacchio et al. (2012); Crupi et al. (2020); Dodourova & Bevis (2014); Doh & Kim (2014); Doloreux et al. (2023); Fukugawa (2018); Goduscheit & Knudsen (2015); Goduscheit & Knudsen (2015); Li et al. (2023); Prodi et al. (2022); Ricci et al. (2021); Tremblay & Yovo (2015); Zangiacomi et al. (2020); Benitez et al. (2020); França et al. (2022); Kahle et al. (2020).
	Consultants & Technology Providers Technology Transfer Centers (TTCs) Research Institutes	*Innovation facilitators:* • Facilitate joint R&D projects • Execution of activities for new technological knowledge generation • Strategic support in technology and organization strategy • Knowledge dissemination • Technology transfer services • Business support	
	Systematic-meta intermediary	*Technology capacity builders:* • Co-regulation of collaborations • Co-management of the coordination and governance system of collaborations • Cross-domain knowledge exchange between intermediaries • Knowledge integration among collaborating actors • Tailoring digital solutions for SMEs' specific needs • Scaling up the technology and innovation processes of SMEs	
Suppliers & Peer SMEs	Competitors Industry-specific SMEs	• Complementary skills and knowledge for technological development • Combined effort for achieving economic, market,	AL-Khatib et al. (2024); Benhayoun et al. (2020); Bharati & Chaudhury (2010); Chipika & Wilson (2006); Dodourova & Bevis (2014);

(*continued on next page*)

Table 4 (*continued*)

Actors	Types	Role of actors	Relevant papers
		and technological benefits	Ferneley & Bell (2006); França et al. (2022); Haug et al. (2023); Hervas-Oliver et al. (2021); Kahle et al. (2020); Khurana et al. (2022); Kolade et al. (2019); Radicic et al. (2019); Scuotto et al. (2017); Zhang (2024).

technologies' implementation (Mawson & Brown, 2017).

Similarly, interactions with industrial networks also have been a determinant of digital technology adoption, as the diversity of collaborative partners positively impacts product and process innovations through digital technologies (Soluk et al., 2023). Such collaborations help SMEs overcome cost, knowledge, market, and infrastructural barriers (Kolade et al., 2019); enhance top management's commitment to deploying I4.0 technologies (Wadhwa et al., 2017); and utilize I4.0 technologies in organizational operations and processes.

Similarly, intermediary organizations' network foresight strengthens network relationships, minimizing challenges from collaborations concerning technology development among SMEs. Such collaborations positively affect assimilation of operation control software among SMEs (Bharati & Chaudhury, 2010), positive impact technological innovations (Doh & Kim, 2013), enhance smart manufacturing (Shukla & Shankar, 2022), and increase capabilities related to additive manufacturing (Hervas-Oliver et al., 2021). To sum up, collaborations with different core values and network actors help SMEs acquire new types of technological knowledge to develop their technological orientation toward digital transformation.

The explored knowledge is exploited through organizational knowledge management structures that channel external knowledge to increase SMEs' technological learning and capabilities. Technological learning is a result of combining knowledge absorption and dissemination to achieve and evaluate technological fitness. It includes testing and trials of digital solutions, accelerated by the organization's existing operational capabilities and technology strategy. Such processes lead to SMEs improving their technological infrastructure, capabilities, and digital transformation processes. Digital transformation is conditional on an organization's internal capabilities and the role of leadership's strategic foresight. Most SMEs improve their basic technological performance; however, advanced stages of digital transformation (i.e., new digital products and services) require a long-term commitment and repetitive learning on technologies for business value, and only SMEs that meet such conditions reach the advanced stages (Sony et al., 2024). Digital transformation of products and services can act as a point of departure for the digital transformation of SMEs' business models, improving SMEs' understanding of new technologies' business value and potentially generating big data, which can be instrumental in business model-level digital transformation. Such iterative learning requires not only internal capabilities, but also scaling up existing digital infrastructure, technological capabilities, and reconfiguration of innovation strategies (Kiron & Kannan, 2018). Digital transformation of products, services, and business models offers SMEs new big data to identify the needs associated with collaborators, configurations in innovation strategies, complementary skills, and analytics on business performance. Data analytics offers new types of capabilities to SME management in terms of quantifying business indicators and matrices, thereby increasing the organizational learning process (Lee et al., 2019). Figure 8 outlines knowledge exploration and exploitation for SMEs' digital transformation through collaborations between core value and network actors.

(II) Ecosystem and innovation platform-based collaborations

This subsection explains how SMEs *explore* and *exploit* technological knowledge through ecosystem and innovation platform-based collaborations.

Ecosystem and platform-based collaborations are much more dynamic and contain specific characteristics, i.e., an anchor tenet actor or orchestrator is compulsory, as actors express untraded interdependencies, share the same value and fate, and co-evolve their roles during different phases of an ecosystem (Hafeez et al., 2021; Shahzad & Hafeez, 2022). These characteristics play an important role in the knowledge exploration and exploitation process among ecosystem actors. Such collaborations enable participants to develop multiple resources and skill complementarities (Suh & Sohn, 2015; Wang & Bai, 2024), as well as achieve high efficiency in I4.0 technology implementation (Estensoro et al., 2022) by compensating for SMEs' internal resource and skills limitations. Entrepreneurial ecosystem collaborations systematically help SMEs integrate disruptive technologies for business model innovation, leading to organizations' digital transformation. Such collaborations are more dynamic and facilitate SMEs' resource integration and cocreation of I4.0 technologies-based solutions (Benitez et al., 2020), as well as systematic transitions toward I4.0 technologies (Prodi et al., 2022), while enhancing understanding of the convergence between infrastructure and basic technologies, leading to SMEs developing complementary products and services (Suh & Sohn, 2015), and forming collective perceptions and assessments of digital artifacts and other related infrastructure between collaborating actors. SMEs that are better-placed within ecosystem collaborations have improved sensing and seizing capabilities to integrate digital technologies, thereby improving their micro-foundations to integrate disruptive technologies for digital transformation through ecosystem collaborations (Scuotto et al., 2023).

Aside from ecosystem collaborations, recent extant studies have revealed that platform-based collaborations increasingly focus on supporting technology infrastructure among SMEs through cocreation and specialized partnerships (Shukla & Shankar, 2022). They also demonstrate that technology infrastructure support is a key factor in adopting and implementing digital solutions in smart manufacturing systems, comprising tools and systems for data management, automation, and integration of new technologies. Berkowitz and Souchaud (2024) highlighted the importance of crowdfunding platforms in implementation of blockchain technologies in SMEs. Similarly, industrial Internet platforms act as a crucial factor for knowledge empowerment in SMEs' digital transformation (Li et al., 2023), offering customized digital solutions to address SMEs' needs and challenges, thereby helping companies resolve industry-level issues and enabling their digital transformation (Li et al., 2023).

During Collaborative Model II, collaborations extend beyond transaction-based bilateral activities. Such collaborations enable SMEs to develop strategic selectivity, allowing them to allocate resources effectively and leverage collaborating partners' external competencies (Ates & Acur, 2022). Ecosystem collaborations' unique features include actors' interdependencies, roles and capabilities' co-evolution, and availability of complementary skills and resources throughout various collaborative stages (e.g., from basic to advanced stages). For example, through ecosystem collaborations, SMEs can evaluate their own and actors' existing competencies and resource availability, directing efforts toward a common value through acquiring hardware (Internet of Things [IoT] and sensor technologies), software support (cloud services and big data analytics), and integration capabilities to develop smart product systems (Benitez et al., 2020; Kahle et al., 2020). Ecosystem actors proactively work on knowledge creation and dissemination related to artificial intelligence (AI) for smart products, system modularity to connect various subproducts as add-ons, service development and operation to achieve smart specialization, and knowledge about

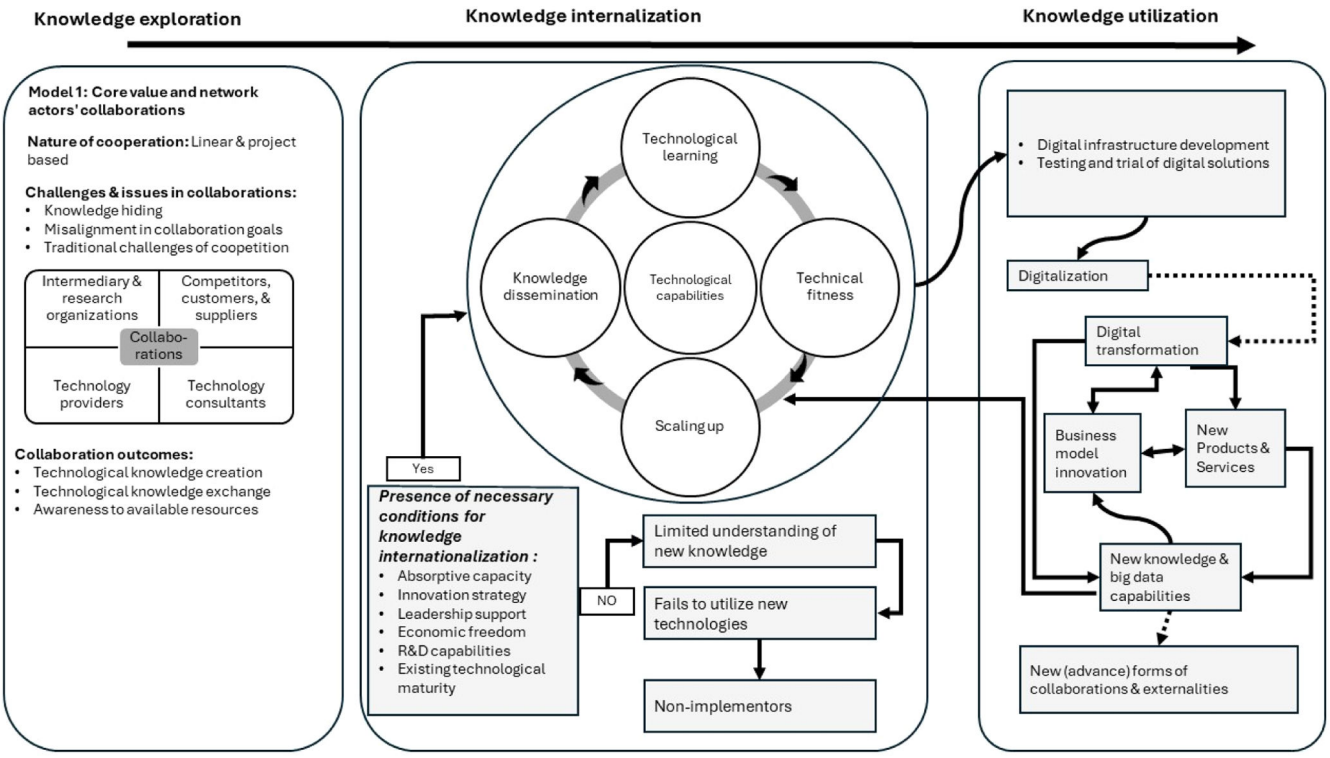

Fig. 8. The core value and network actors' collaborations.

pursuing external funding, particularly for resource-constrained SMEs (Kahle et al., 2020). Berkowitz and Souchaud (2024) spotlighted ecosystem collaborations' evolutionary nature, noting the emergence of actors during different phases: During the first phases, meta-organizations provide resources, governance structures, and advocacy for business angels. During the second phase, these organizations contribute to the platform's development by constructing a regulatory framework and offering training. During the final phase, a network of intermediary organizations devises a legal framework for blockchain financing, mastering blockchain technologies and bridging the gap between entrepreneurs and IT experts (Berkowitz & Souchaud, 2024). As a result of co-evolution and multiple layers of collaboration among various actors in ecosystem and platform collaborations, SMEs were able to understand and adapt to technological convergence driven by large firms (Cenamor et al., 2019).

Compared with other models, SMEs have enjoyed greater success in

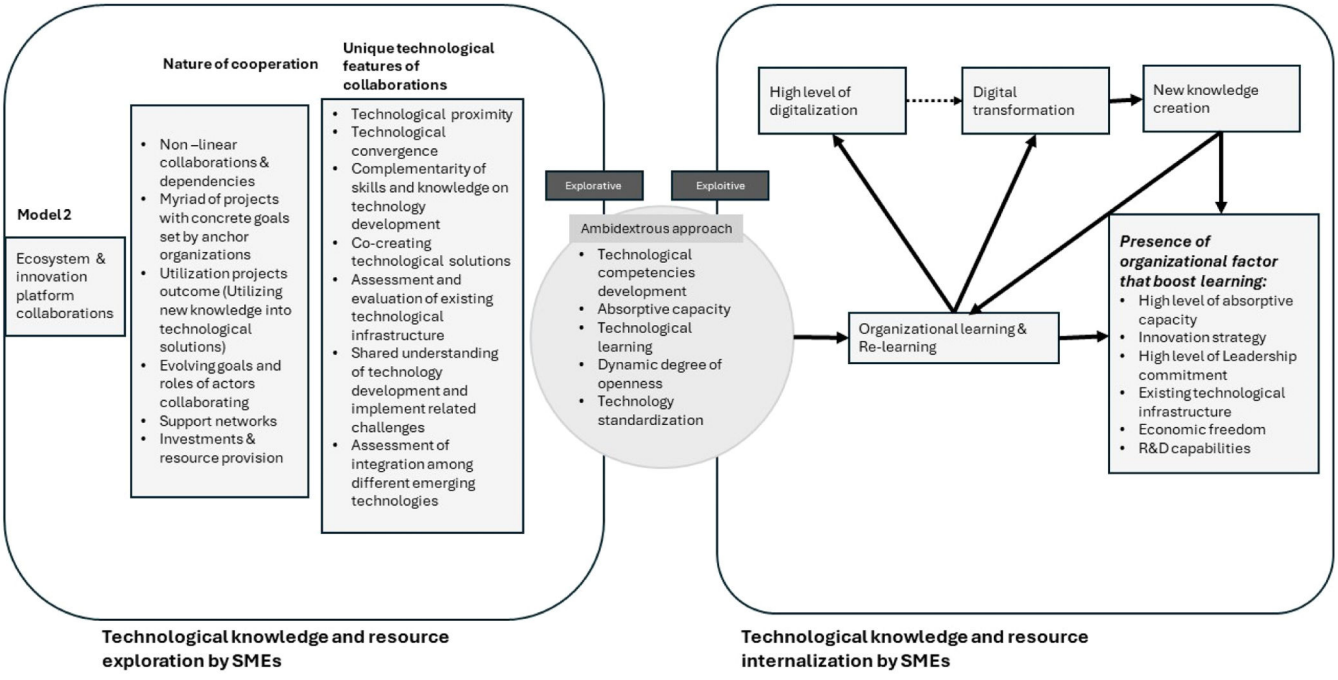

Fig. 9. Ecosystem and innovation platform-based collaborations.

achieving sustained digital transformation through ecosystem and platform collaborations due to an ambidextrous approach to knowledge management (knowledge exploration and exploitation). In this approach, SMEs and other actors jointly create new knowledge and subsequently internalize and utilize new knowledge through collective actions and cocreation. Interestingly, in such collaborations, SMEs are not left alone to internalize and utilize external knowledge, instead, they are provided with support, resources, and complementary skills, and are engaged in projects to learn by doing (Shahzad & Hafeez, 2023). They gain practical support and mechanisms to absorb new knowledge, gain orientation on real case technology examples, cocreate solutions, and learn about integrating different technologies, data, and technology standardization to facilitate big data utilization and new business models based on technologies. Figure 9 depicts knowledge exploration and exploitation for SMEs' digital transformation through ecosystem and innovation platform-based collaborations.

Internal factors in knowledge exploitation

Existing capabilities, internal infrastructures, and innovation processes are important determinants in the successful exploitation of explored technological knowledge. A critical evaluation of papers reveals that exploitation of newly generated knowledge does not automatically facilitate SMEs' digital transformation. Instead, it requires certain internal factors that we refer to as preconditioning and facilitating factors, i.e., they act as preconditioning factors in the collaborative model (I) and facilitating factors in the collaborative model (II). These factors are categorized further into four categories: *organizational capabilities; micro-foundations; organizational strategies and culture*; and *operational capabilities*.

Organizational capabilities

It has been established that organizational capabilities are crucial for organizations to internalize externally acquired knowledge. Specifically, dynamic capabilities have been identified as one of the most influential factors that help SMEs actively integrate external knowledge into their internal organizational structures (Ates & Acur, 2022; Cadden et al., 2023; Pundziene & Geryba, 2023). Dynamic capabilities also enable organizations to reconfigure established routines and processes to incorporate new knowledge into information-processing systems and embed it into strategic decision-making—essential for achieving desired outcomes in digitalized products, services, and business models. Innovative capabilities—such as strategic foresight, resilience, and absorptive capacity—act as internal knowledge bases for SMEs, facilitating absorption and utilization of new technological knowledge in digital offerings (Benhayoun et al., 2020; Muscio, 2007; Tranekjer & Knudsen, 2012). Moreover, agility is a critical capability that enables SMEs to sense and respond promptly to external challenges and opportunities in the business environment (Chan et al., 2019; Han & Trimi, 2022). Researchers also have emphasized that strategic foresight, experimentation, and risk-taking are vital for organizations to internalize and utilize external knowledge. Specifically, strategic foresight helps managers set targets and directions for utilizing new knowledge, while experimentation and risk-taking are essential for tests and trials of new technological solutions (Heger & Boman, 2015). The internalization of technological knowledge necessitates various types of organizational capabilities.

Micro-foundations

Like organizational capabilities, the literature widely discusses micro-capabilities' importance in knowledge internalization and utilization for SMEs' digitalization. Micro-foundations also have been documented as skills and competencies of individuals working within the organization. The sample paper analysis identified that individuals' dynamic capabilities, entrepreneurial persistence, entrepreneurial orientation, knowledge, and social skills as leaders, skilled employees, and human and social capital are key micro-foundations. Leaders' entrepreneurial orientation tends to enhance leadership support for innovative and forward-looking approaches (Cadden et al., 2023; Kiani et al., 2022). Simultaneously, it helps organizations create innovative work cultures that, combined with persistence, work synergistically to achieve organizational goals (Christofi et al., 2024). Researchers have explained that such innovative behavior is beneficial for knowledge exploration and, consequently, knowledge exploitation in technological solutions (Chung & Kim, 2023). Developing technological solutions and testing new knowledge in concrete solutions require top management commitment and persistence; therefore, leaders' entrepreneurial persistence and orientation are among key preconditions for knowledge exploitation. Similarly, skilled employees and organizations' human resources play important roles in recognizing, interpreting, and utilizing new knowledge in digital solutions (Ietto et al., 2022; Son & Zo, 2023; Tremblay & Yovo, 2015).

Organizational strategies and culture

We also found that organizational strategy is key in successfully transforming technological knowledge into digital solutions. Our review indicates that the papers we examined identified three strategies: technology implementation strategies; innovation strategies; and R&D strategies. Combining and aligning new knowledge with implementation strategies is essential for yielding tangible outcomes through knowledge exploitation. A well-defined implementation strategy includes clear objectives, timelines, resource allocations, and expected outcomes from new technology adoption (Ho et al., 2016; Kim et al., 2016). The innovation strategy is crucial for assessing and reconfiguring existing innovation processes based on newly acquired knowledge (Bonesso et al., 2011; Caetano & Amaral, 2011). The innovation strategy also encompasses establishing collaborative mechanisms and processes for selecting, filtering, and utilizing knowledge (Madrid-Guijarro et al., 2009); thus, it is a vital factor in exploiting external knowledge within organizational digital innovation systems. Finally, some researchers contend that R&D strategy is a component of innovation strategy, as the former pertains to inbound and outbound innovations. However, concerning digital transformation, the R&D strategy pertains to companies' strategic plans and decisions in developing and testing technological solutions in-house or through outsourcing. The R&D strategy influences SMEs' knowledge exploitation processes (Garrigos et al., 2011; Park et al., 2022).

Operational capabilities

Operational capabilities are related to utilization of organizational resources and processes to achieve desired outcomes effectively (Benhayoun et al., 2020). In the context of digital transformation, organizations' existing digital infrastructure can be viewed as operational capabilities. A detailed analysis reveals that technological infrastructure, intensity, and readiness, as well as digital maturity, are key dimensions of operational capabilities in SMEs' digital transformation. Operational capabilities are critical in determining the extent of technological development and successful knowledge utilization for digital transformation (Khin & Hung Kee, 2022; Maroufkhani et al., 2023). Organizations with mature technological infrastructures can decode complex technological concepts and utilize knowledge to develop new solutions while improving organizational operations and processes. Similarly, technology readiness enables management to translate new learning into testing and trials of new digital solutions (Ballestar et al., 2020; Koo & Lee, 2019). The technology intensity of industry moderates the rate and speed of technology implementation and accelerates digital transformation within industries (Petruzzelli et al., 2022; Park & Ghauri, 2011). Table 5 presents preconditioning factors for knowledge exploitation.

Table 5
Preconditioning factors for knowledge exploitation.

Pre-conditions	Description	Cited papers
Organizational capabilities	• Organizational agility • Organizational adaptability • Organizational ambidexterity • Technological capabilities • Dynamic capabilities • Strategic foresight • Experimentation • Risk-taking capability • Innovation Capabilities • Opportunity-spotting capabilities • Organizational readiness • Resilience • Absorptive capacity • Specialized competencies	AL-Khatib et al. (2024); Ates & Acur (2022); Benhayoun et al. (2020); Chan et al. (2019); Chan et al. (2019); Chung & Kim (2023); Del Giudice et al. (2021); Estensoro et al. (2022); Han & Trimi (2022); Heger & Boman (2015); Khin & Kee, (2022); Khurana et al. (2022); Koo & Lee (2019); Maroufkhani et al. (2023); Muscio (2007); Pundziene & Geryba. (2023); Ricci et al. (2021); Soluk & Kammerlander (2021); Soluk et al. (2023); Tranekjer & Knudsen (2012).
Microfoundations	• Individual substantive dynamic capabilities • Individual adaptation capabilities • Human resources capital • Strategic leader's entrepreneurial persistence • Entrepreneurial orientation • Individual change dynamic capabilities • Top management support • CEO background and knowledge • Skilled and network-savvy entrepreneurs • Internal Social Capital	Scuotto et al. (2021); Madrid-Guijarro et al. (2009); Cadden et al. (2023); Chipika & Wilson (2006); Christofi et al. (2024); Chung & Kim (2023); Hansen et al. (2024); Ietto et al. (2022); Kiani et al. (2022); Muscio (2007); Park & Ghauri (2011); Son & Zo (2023); Tremblay & Yovo (2015); Wadhwa et al. (2017).
Operational capabilities	• Digital maturity • Technological infrastructure • Technology intensity of the industry • Technological readiness	Gupta & Barua (2016); Haug et al. (2023); Shukla & Shankar (2022); Petruzzelli et al. (2022); Ballestar et al. (2020); Benhayoun et al. (2020); Gutierrez et al. (2015); Hansen et al. (2024); Maroufkhani et al. (2023); Park & Ghouri (2011).
Strategies and culture	• Technology implementation strategy • R&D Strategy • Innovation strategy • Knowledge sharing culture	Chung & Kim (2023); Shukla & Shankar (2022); Madrid-Guijarro et al. (2009); Bonesso et al. (2011); Caetano & Amaral (2011); Ho et al. (2016); Kim et al. (2016); Park & Ghauri (2011); Yao et al. (2020); Zangiacomi et al. (2020); Garrigos et al. (2011); Park et al. (2022).

Discussion

The content analysis of collaborative frameworks in knowledge management for SMEs reveals two distinct approaches, including (I) core value and network actors' collaborations and (II) ecosystem and innovation platform collaborations. Each of these models provides valuable perspectives on how SMEs acquire, assimilate, and apply technological knowledge to drive their digital transformation.

Core value chain network actors' collaborations and digital transformation

The first model revolves around linear and project-based collaborations with key value chain actors, such as customers, suppliers, and technology providers. From the perspective of the KBV, these collaborations typically are structured and goal-oriented, directed toward exploring external technological knowledge. While possessing technological knowledge is an immense resource for SMEs, the market for technological knowledge is underdeveloped (Ricci et al, 2021), prompting SMEs to seek such knowledge in their external environment actively (Mahdiraji et al., 2023; Haug et al., 2023). These organizations often consolidate their core value chain actors to explore new technological knowledge to scan for new digital opportunities, possibilities, and industry-specific technological solutions (Stentoft et al., 2021). In this exploration process, the success of knowledge acquisition and utilization often is determined by the scale of close social, technological, and economic proximity among collaborating actors (Marullo et al., 2024). Actors with similar technological infrastructures, digital maturity, market goals, and high levels of trust are more inclined toward developing strategic partnerships and cocreating new technological solutions, thereby minimizing knowledge hiding and reducing fears of opportunistic behavior among collaborators (Hwang, 2023; Tremblay & Yovo, 2015). Furthermore, these strategic collaborations form formal collaborative networks that enable SMEs to overcome barriers related to cost, knowledge, market, and infrastructure concerning technological innovations (Kolade et al., 2019). The aspect of strategic collaborations is also important for knowledge exploitation. In such collaborations, actors support one another in internalizing new knowledge by aligning digital infrastructures, implementing new technologies, and integrating different technologies to improve supply chain performance (Scuotto et al., 2017). However, challenges such as knowledge hiding and misaligned collaboration goals often arise, limiting these collaborations' effectiveness. These relationships' structured nature, while beneficial for incremental innovation, restricts SMEs from fully adapting to rapidly evolving technological landscapes (Wei et al., 2024).

In addition to the challenges of knowledge hiding, the static roles inherent in these collaborations often create a delicate balance between collaboration and competition. Del Giudice et al. (2021) explored the limitations associated with coopetition further, highlighting the difficulties that SMEs face in balancing exploration and exploitation within such relationships.

For SMEs to exploit external knowledge, they require strong internal capabilities, including organizational agility and the ability to reconFig. resources dynamically. This is particularly crucial, given that organizational rigidity often impedes internalization of new knowledge, a point supported by Chan et al. (2019), who suggested that digital transformation efforts' success hinges on developing innovative capabilities within SMEs. Extant studies have confirmed that boundary-spanning activities, such as collaborations with external actors, reduce organizational rigidity and promote organizational adaptability, thereby increasing organizational agility (Chan et al., 2019). External collaborations introduce SMEs to new ideas and opportunities (exploration), enticing them to implement new solutions and technologies for various purposes (exploitation). Achieving organizational ambidexterity is important to maintaining organizational agility and developing innovative capabilities through external collaborations (Del Giudice et al., 2021; Dezi et al., 2021). Similarly, core value chain collaborations enable SMEs to tap into external resources to mitigate internal resource constraints, complement internal capabilities for innovations, and develop strong relational capabilities that ensure effective communication for market volatility, thereby enhancing operational and strategic agility (Troise et al., 2023). Collaboration with core value chain actors can enable SMEs to achieve operational and strategic agility. By achieving operational agility, SMEs can mobilize their internal digital resources and redesign their operations quickly to meet new technological demands, while integrating new technologies into their existing systems (Chan et al., 2019). Strategic agility encourages SMEs to sharpen their strategic sensitivity to identify and evaluate digital opportunities, achieve resource fluidity to integrate solutions

(Han & Trimi, 2022), and enforce competence development strategies parallel to operational technological implementations to achieve long-term digital transformation goals (Hansen et al., 2024). For example, the availability of emerging technologies and technological convergence between different actors on innovation platforms enable participating SMEs to achieve modularity and test combinations of technological components, thereby achieving operational agility (Han & Trimi, 2022). In the long run, operational agility allows SMEs to develop strategic agility in terms of forming new collaborations (Han & Trimi, 2022), cocreating within collaborative networks I4.0, and integrating new technologies in business offerings (Sassanelli & Terzi, 2022).

Similarly, the literature underscores the importance of preconditions for knowledge internalization. SMEs that succeed in these collaborations typically possess strong organizational capabilities, operational capabilities, robust micro-foundations (e.g., leadership skills and employee competencies), and alignment between knowledge management strategies and business goals. This is validated by Estensoro et al. (2022) and Mubarak and Petraite (2020), who argued that the transition to I4.0 requires a combination of internal capabilities and external support from collaborative networks. These collaborations' structured, project-based nature may foster business model innovation in the short term, but limitations in scalability and adaptability prevent SMEs from achieving breakthrough innovations.

Thus, in Collaborative Model I, knowledge exploration is a combined activity, in which SMEs collaborate or form interorganizational collaborations to search for new knowledge, and knowledge exploitation is characterized by strong internal capabilities and condition factors.

Ecosystem and innovation platform collaborations for digital transformation

From the perspective of a KBV, ecosystem and innovation platform collaborations offer a more dynamic and ambidextrous approach to knowledge exploration and exploitation in SMEs. These collaborations are nonlinear, with multiple actors participating in the cocreation of technological solutions. Unlike core value chain collaborations' static nature, ecosystem-based collaborations involve continuous evolution of roles and goals, allowing SMEs to remain adaptable to changing technological demands. This co-evolution process leads SMEs and other actors to adopt an ambidextrous approach toward knowledge management, sharing and acquiring new knowledge in the same collaborations, and exploiting new knowledge through multilayer and multi-actors' collaborations to develop technological solutions jointly and achieve business model-level configurations and technological maturity (Hafeez et al., 2025). For example, Estensoro et al. (2022) underscored ecosystem collaborations' importance during various stages of digital maturity, enabling SMEs to enhance their learning about I4.0 technologies throughout different stages of digital maturity. This adaptability allows SMEs to engage in exploratory innovation by acquiring new technological knowledge that often is inaccessible through more structured, linear collaborations. Adaptability has been linked further with organizational ambidexterity. Del Giudice et al. (2021) argued that early adopters of technology and innovations share a common approach: ambidextrous exploration and exploitation of new solutions. Organizational ambidexterity is also important for SMEs to overcome their limitations related to technological investments (Scuotto et al., 2017), as well as achieve technological breakthroughs. Ecosystem collaborations challenge SMEs' conventional approaches and encourage them to adapt to continuous changes and adjustments in the interactions' structural and intellectual landscape (Pelletier & Cloutier, 2019; Scuotto et al., 2023). In response to continuous evaluation and external feedback, SMEs develop their innovations and organizational agility (Han & Trimi, 2022). Thus, compared with core value chain actors' collaborations, ecosystem and platform collaborations enhance SMEs' agility by enabling these organizations to sharpen their sensing capabilities, exposing them to wider industry trends and arising opportunities, thereby increasing their knowledge convergence and resource fluidity while receiving continuous support from other actors in pursuing the core value of collaborations.

Ecosystem collaborations support this ambidextrous knowledge management approach further, enabling SMEs to leverage complementary skills and resources from other actors within the network, including larger anchor organizations and research institutions. The dynamic cocreation of knowledge within these ecosystems aligns with Mahdiraji et al. (2023) and Mubarak et al. (2021), who highlighted the role of intermediary organizations and government support in facilitating transfer of technological knowledge to SMEs. This boundary-spanning approach is particularly effective in overcoming infrastructural and operational challenges that often hinder SMEs from adopting digital platforms. The iterative nature of learning and relearning within these ecosystems is a significant factor in enabling SMEs to develop technological maturity. SMEs that participate in innovation platforms benefit from continuous adaptation, ensuring that they remain competitive in industries characterized by rapid technological advancement (Corvello et al., 2023). Haug et al. (2023) discussed how SMEs involved in additive manufacturing (AM) networks are better-equipped to build internal capabilities by drawing on knowledge and resources available within the ecosystem. This knowledge internalization process is not limited to absorbing external knowledge, but also involves active participation in its cocreation, thereby strengthening SMEs' position within the ecosystem.

Utilization of technological knowledge in ecosystem collaborations is also more robust compared with the core value chain model. By fostering open knowledge exchange and encouraging development of new products and services, these collaborations allow SMEs to achieve high digital transformation levels. Haug et al. (2023) highlighted further that SMEs engaged in knowledge networks to gain AM experience sustained competitive advantages, as they can leverage both internal and external knowledge resources effectively. This ability to adapt and innovate continuously is a key strength of ecosystem-based collaborations, making them a more viable option for SMEs seeking to achieve long-term digital transformation. By comparison, core value chain collaborations' linear nature offers fewer opportunities for sustained innovation. Although these collaborations are effective for incremental technological improvements and short-term business model innovation, they lack the dynamic flexibility required to thrive in an increasingly digital and interconnected business environment. However, ecosystem collaborations provide a more comprehensive framework for fostering organizational learning, innovation, and digital maturity. Figure 10 presents an integrated framework for knowledge exploration and exploitation for SMEs' digital transformation.

Conclusion

Theoretical implications

This research emphasizes the importance of external knowledge exploration and exploitation for SMEs' digital transformation. Through boundary-spanning activities, SMEs can access new technological knowledge and complement resources to improve their internal digital infrastructures, technology maturity, and technological learning pertinent to the digital transformation of processes, offerings, and business models (Crupi et al., 2020; Haug et al., 2023; Ricci et al., 2021). Boundary-spanning activities enhance SMEs' collaborations with various external stakeholders, such as customers and suppliers' networks, competitors, intermediary organizations, and government-representing organizations (Hafeez et al., 2025). For example, customer and supplier networks are central to pushing and encouraging SMEs to utilize the latest technologies for organizational innovations (Del Giudice et al., 2021; Estensoro et al., 2022). SMEs can learn from competitors in well-structured and properly managed coopetition-based collaborations. A successfully managed coopetition

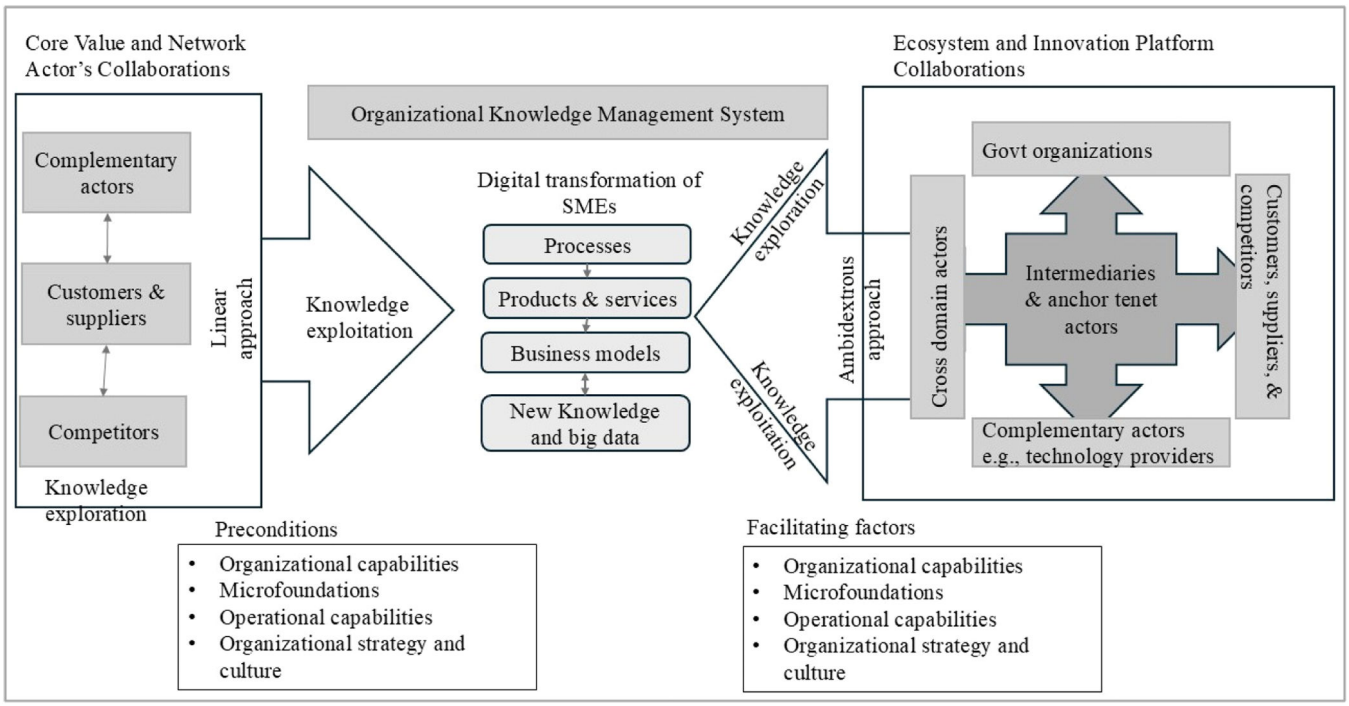

Fig. 10. Integrated framework on knowledge exploration and exploitation for SMEs' digital transformation.

can earn higher technological benefits for SMEs due to close technological and economic proximity. Similarly, intermediary organizations are keystone actors in SMEs' external environment. Intermediary organizations have dynamic and varying roles for setting up, executing, managing, and governing collaborations between business and nonbusiness actors. Intermediary organizations provide knowledge-brokering services, facilitate innovation processes, enable knowledge and technology transfer, and assume a greater role by enabling sociotechnical transitions' larger role. This advanced role is executed by systematic intermediary organizations, which indirectly act as capacity-building actors for SMEs in the digital transformation of their offerings and business models (França et al., 2022; Kahle et al., 2020). We also posit that government organizations and representative bodies' initiatives, such as favorable policymaking and financial support, are important in promoting and articulating a collaborative environment for technology testing and implementation among resource-constrained SMEs.

It has been demonstrated that SMEs utilize two distinct modes of collaboration for their digital transformation: (I) core value chain network actors' collaborations and (II) ecosystem and innovation platform-based collaborations. The nature of collaborations, relationships among actors, exchanges of knowledge and resources, and dependencies among actors vary between the two collaborative models. This variation affects SMEs' capacity to acquire, internalize, and utilize new knowledge for digital transformation of their processes, offerings, and business models. For example, in Collaborative Model I, knowledge exploration and exploitation for digital transformation are viewed as linear models, having certain organizational capabilities, micro-foundations, operational capabilities, and organizational strategies as preconditioning factors for knowledge exploitation. In Collaborative Model II, SMEs adopt an ambidextrous approach as a nonlinear process for knowledge exploration and exploitation for digital transformation. In such a model, organizational capabilities, micro-foundations, and operational capabilities are moderating and mediating factors, rather than preconditioning. Finally, the integrated framework (Figure 10) synthesizes literature on external collaborations for knowledge exploration and exploitation (Ricci et al., 2021; Mahdiraji et al., 2023; Haug et al., 2023; Suh & Sohn, 2015) for SMEs' digital transformation (Scuotto et al., 2017; Mubarik et al., 2022; Del Giudice et al., 2021; Estensoro et al., 2022; Hafeez et al., 2025).

Theoretical Contributions

This research also contributes to the literature by providing novel insights on the relevance of the KBV of SMEs' digital transformation. The present study's findings warrant explicit and detailed insights into the interplay between exploratory approaches and exploitative mechanisms for knowledge management in the context of SMEs' digital transformation. We contributed to the literature by demonstrating that external knowledge acquisition and internalization are integral to boundary-spanning activities (Anshari et al., 2022); digital infrastructure and internal capabilities are important for knowledge exploitation (Ben Slimane et al., 2022); customers, suppliers, intermediaries, and government organizations are key external determinants in unique technological knowledge exploration (Ghobakhloo et al., 2022; Ramdani et al., 2022); knowledge exploration aligned with the exploitation process can develop unique dynamic capabilities for digital transformation (Mele et al., 2024); and new knowledge utilization contributes to operational and strategic agility for SMEs' digital transformation (Marino-Romero et al., 2024). Table 6 provides an overview of our contribution to the literature gap.

Practical implications

Our research presents practical implications for SME management, experts from intermediary organizations, and policymakers from government institutes.

SME Management

- SMEs that aim to leap forward to the digital transformation of offerings and business models can shape creation of their necessary preconditions in advance actively. They should consider proactively scanning their external environments to find possible support and complementary skills and resources for digital transformation.

Table 6
The present study's theoretical contributions.

Authors	Key Findings	Limitations & Research Gap	Our contributions
Anshari et al. (2022)	• The positive link between digital ecosystem readiness for I4.0 adoption • Relevance of Knowledge management for open innovation implementation • Government as a protector of market regulations	Lack of analysis of technological knowledge exploration and exploitation. Limited to the Indonesian context.	The ambidextrous nature of knowledge exploration and exploitation is a unique feature of ecosystem collaborations promoting SMEs' digital readiness. In some contexts, government organizations act beyond the protection of market regulators as innovative facilitators through policies and funds.
Slimane et al. (2022)	• Digital infrastructure and digital manager relevance for digital transformation • Reconfiguration of organizational and managerial mechanisms • Top Management is responsible for digital change management	Shallow analysis of the relevance of knowledge management for Digital transformation.	Digital infrastructures, digital leadership, strategic reconfigurations, and top management social capital are influenced by the SME's capacity to collaborate, and these factors act as preconditions for technological knowledge exploitation.
Ghobakhloo et al. (2022)	• Technological determinants • Organizational determinants • Environmental determinants • I4.0 adoption roadmap	Despite explaining environmental determinants, research lacks an in-depth evaluation of SMEs' various interactions and their relevance for the adoption of I4.0 technologies.	Customers, suppliers, and competitors are core actors in environmental determinants for developing solutions related to I4.0 adoption. Intermediary organizations of various types are increasingly emerging as capacity-building actors in the boundary-spanning activities of SMEs.
Ramdani et al. (2022)	Overview on: • Digital technologies • Theories for Digital Innovations • Contextual and organizational factors for digital innovations	Lacks in-depth analysis to show how SMEs interact with external actors and their role in digital transformation.	Collaboration with external actors provides SMEs with knowledge and resources to test and trial new technologies. Co-creation and co-development of technological solutions lead these organizations to develop digital innovations.
Mele et al. (2024)	• Micro-foundation of dynamic capabilities • Dynamic capabilities for value creation • Dynamic capabilities for • Digital transition • Dynamic capabilities for "data-driven organizations • Dynamic capabilities for digital transformation in SMEs and family firms	There is a lack of details on how SMEs leverage their external networks to acquire relevant knowledge and what kind of support they receive from external actors. Missing details on the intricate process of knowledge exploration to exploitation for digital transformation.	A combination of knowledge exploration, aligned with the exploitation process, can develop unique dynamic capabilities for digital transformation.
Marino-Romero et al. (2024)	• Digital transformation promotes agility in organizational processes. • Development of digital capabilities • Strategies for scaling up digital technologies	Lack of analytical depth in leveraging dynamic capabilities for knowledge acquisition and internalization. Provide a bibliometric overview of the studies, with a missing systematic literature analysis.	New knowledge exploration and its utilization led SMEs to develop operational and strategic agility for digital transformation.

- Digital transformation requires infrastructural, operational, and managerial readiness for successful technology implementation. SME management must align these functions with technology and innovation strategies to maximize output from technology implementation and utilization.
- SME management, particularly top management, should place greater emphasis on developing technical and digital competencies. These competencies will support development of dynamic capabilities within business organizations, enabling them to thrive in current and future markets, as well as navigate utilization of technologies for business purposes.
- SME management should be open to collaborations with external networks to acquire new knowledge on implementing emerging technologies. Such collaborations can compensate for low internal technological maturity and help SMEs achieve a competitive advantage.
- To overcome internal resource limitations, SMEs that enter into ecosystem collaborations to acquire access to shared resources, such as machinery, and promote shared technological infrastructure can increase interoperability, thereby alleviating financial constraints on advanced technology utilization.
- SME management is encouraged to collaborate with universities and research institutions to utilize digital innovation labs and dedicated expertise to accelerate digital transformation.
- SME managers need to articulate a formalized strategy to make capacities of their human capital, associated learning processes, and assumption of risks more effective. Managers should be encouraged to conduct boundary-spanning activities that stimulate new and successful business models within their organizations.
- Designing and communicating a digital strategy provides a success story that redirects employees toward digital transformation; thus, having a strategy roadmap for digital transformation is suggested for SME management.

- Resource-constrained SMEs are encouraged to collaborate with different ecosystem actors and participate in online communities to acquire external expertise that is essential for digital transformation.

Policymakers

- The government should provide tailored support programs and enhanced access to education and training for SMEs. The aim should be to prioritize long-term economic development and capacity building for effective networking among SMEs.
- For disruptive technologies, the government shall provide incentives for investment in new technologies, as well as make technical support and training programs available. This support can increase SMEs' willingness to adopt disruptive technologies and leverage their potential benefits.
- Policymakers shall consider the importance of social, behavioral, and relational factors alongside technical aspects in digital transformation efforts. Policymakers can leverage these insights to develop and strengthen IT-related support agendas tailored to SMEs' needs, particularly smaller ones, through customized training programs, coaching initiatives, and other support mechanisms.
- Public support programs should be demand-led, catering to traditional SMEs' diverse needs. Subsidies and financial support for SMEs can smooth out implementation of disruptive technologies in SMEs' manufacturing processes; the government should provide tailored programs.
- Policymakers should be aware of technology transfer centers and their activities, identify centers that can fulfill the boundary-spanning role, and support initiatives that aim to increase their effectiveness by providing incentives to technology transfer centers and enhancing their human capital and social capabilities, enabling them to orchestrate numerous interfaces with cross-disciplinary teams and stakeholders.
- Government policymakers are encouraged to provide customized sector-specific support strategies to strengthen internal financing, such as tax benefits and subsidies, and enhance external collaboration using intellectual properties, such as licensing.
- Policymakers should revise regulations to facilitate digital transformation, encourage investments in infrastructure and technology, and develop programs to improve digital platforms' operational management.

The study's limitations

This study provides valuable insights into SMEs' digital transformation; however, several limitations should be considered when interpreting the nuances of this research. Methodologically, the reliance on an SLR inherently depends on the quality and scope of the selected literature. The decision to focus on ABS-ranked journals with a minimum ranking of Level 2 may have excluded relevant insights from lower-ranked journals, conference proceedings, and published theses, i.e., this choice might have narrowed our findings' scope, yet our outcomes' validity is justifiable with the large sample size of papers used. Xu et al. (2018) suggested that researchers retrieve a substantial number of papers when analyzing a mature topic, thereby maintaining stringent quality criteria for robust and rigorous findings. However, we encourage future researchers to include gray literature to yield more comprehensive results. Similarly, the use of Scopus and Web of Science databases, while comprehensive, excluded studies from other repositories or regional and specialized journals that could have provided broader perspectives. Furthermore, inclusion of only English-language publications introduces a Western-centric bias, overlooking valuable contributions from non-English-speaking regions. The study also predominantly employed an established theoretical framework, i.e., the KBV, which, although robust, may not have fully captured emerging paradigms or interdisciplinary perspectives on digital transformation. Another potential limitation of a KBV is the overemphasis on knowledge as a key strategic asset, which may overshadow internal organizational dynamics, such as employee training, change management, and resistance to technological adoption. Furthermore, cross-cultural variations in SMEs' digital transformation practices remain underexplored, and the findings may not fully represent diverse socioeconomic contexts. However, KBV captures comprehensive details on the various factors and actors related to the knowledge exploration and exploitation process in digital transformation. It enables researchers to zero in on details of mechanisms of organizational boundary-spanning activities and their linkage with knowledge exploration. Similarly, it provides a powerful lens through which to understand knowledge internalization and utilization for organizational capabilities and innovation development, thereby offering an opportunity to develop a comprehensive understanding of SMEs' digital transformation processes. Moreover, while the findings address sectoral practices, they are generalized across SMEs, potentially overlooking industry-specific nuances. Given digital transformation's dynamic nature, the reliance on published studies from 2004 to 2024 may not have captured the most recent technological advancements or disruptions adequately. Finally, the study lacks empirical validation, relying solely on secondary data, which limits the ability to test the proposed frameworks in real-world scenarios or specific SME contexts. These limitations underscore the need for future research to expand the scope of analysis, incorporate primary data, and explore underrepresented aspects of SMEs' digital transformation journey.

Future research directions

While the extant literature provides valuable insights into the collaborative frameworks and digital transformation strategies employed by SMEs, several avenues for further exploration remain. Addressing these literature gaps would deepen understanding of how SMEs can manage knowledge, foster innovation, and achieve long-term digital transformation more effectively. The following directions are proposed to guide future research:

- Future research aveues for external stakeholders' relevance in digital transformation
  - Future research should focus on understanding the mechanisms that enable SMEs to overcome digital transformation barriers related to scalability within digital ecosystems. This could involve investigating the roles of intermediary organizations, government interventions, and innovation platforms in facilitating resource-sharing and providing support structures for SMEs. Studies that examine how digital platforms and collaborative networks foster scalability would provide actionable insights for both policymakers and practitioners.
  - Given the diverse economic, social, and cultural landscapes in which SMEs operate, future studies should undertake cross-cultural and regional comparisons to explore how knowledge management and digital transformation differ across geographical contexts. Comparative studies could examine how intermediaries and government organizations have different support and resource structures in developed economies vs. those in emerging markets, and how they support SMEs in their digital transformation differently.
  - Understanding local cultural factors' role in shaping SMEs' responses to digitalization could help develop more culturally sensitive and effective strategies.
  - While much extant research has focused on exploring SMEs' capabilities, more research is needed to explore the key capabilities, learning mechanisms, and micro-foundations of intermediary actors that lead SMEs to digital transformation.

- Government support enables SMEs to embark on digital transformation journeys, but extant research on specific policies and incentives that are most effective in fostering SMEs' digital transformation remain scarce. Future research should evaluate the impact from various government interventions—such as tax incentives, grants, subsidies, and digital infrastructure investments—on SMEs' digital growth. Studies that assess how these policies can be tailored to address SMEs' unique needs in different sectors and regions would provide valuable insights for policymakers.

- Future research avenues on internal factors in digital transformation
  - Much of the literature emphasizes the importance of organizational capabilities in internalizing external knowledge, and future studies should consider leadership and micro-foundations' role in this process. Further investigation into how micro-foundations—such as individual competencies, routines, and organizational culture—contribute to effective knowledge internalization could yield practical insights for enhancing SME performance in knowledge-intensive environments.
  - Future research is needed to develop comprehensive metrics that assess digital transformation's impact on SME competitiveness. Such metrics could evaluate changes in market share, operational efficiency, innovation output, and customer satisfaction due to digitalization. By establishing clear benchmarks for digital transformation success, future studies can provide SMEs with actionable insights on measuring and optimizing their digital initiatives for sustained competitive advantage.
  - Future research avenues on methods and contexts
    - To gain a more comprehensive understanding of long-term impacts from digital transformation, future research should employ longitudinal studies that track SMEs' progression through different stages of digital maturity. Such studies could identify critical inflection points at which SMEs either advance or stagnate during their digital transformation journeys. Moreover, they could explore the factors that enable SMEs to transition from early-stage digital adoption to full-fledged digital integration, providing a clearer roadmap for practitioners aiming to sustain digital growth.
    - While much current extant research on knowledge management within SMEs is generalizable, future studies should investigate sector-specific practices, particularly in industries in which digital transformation poses unique implications. For example, industries such as manufacturing, healthcare, and finance face distinct challenges and opportunities in their digitalization efforts. Tailoring knowledge management frameworks to specific sectors would provide more nuanced and actionable recommendations for firms operating in diverse industrial contexts.
    - Future research avenues on sustainability and digital transformation's ethical aspects
      - With the rapid adoption of AI, big data, and automation across SMEs, these technologies' ethical dimensions need to be addressed. Future research should explore technological integration's ethical implications, including issues related to data privacy, algorithmic transparency, and the potential for job displacement. By investigating how SMEs can balance technological innovation with ethical responsibility, scholars can contribute to the development of more sustainable and socially responsible digital transformation strategies.
      - With growing global attention being paid to sustainability, future research should explore how SMEs can integrate sustainable practices into their digital transformation strategies. This could involve examining the intersection of sustainability objectives and digital transformation, particularly how SMEs leverage digital technologies to reduce their environmental impact, optimize resource use, and contribute to broader sustainability goals. Investigating how sustainability-oriented digital transformation can enhance SMEs' competitive positioning while aligning with the United Nations' Sustainable Development Goals (SDGs) would add a valuable dimension to current discourse.
      - Future research also can explore strategies and approaches that lead SMEs in their twin transformation.

CRediT authorship contribution statement

Shahid Hafeez: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Khuram Shahzad:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Petri Helo:** Writing – review & editing, Validation, Supervision, Resources, Conceptualization. **Muhammad Faraz Mubarak:** Writing – review & editing, Writing – original draft, Validation, Conceptualization.

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Supplementary materials

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