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Sustainable Digital Transformation in Small and Medium Enterprises (SMEs)

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ABSTRACT

Small- and medium-sized enterprises (SMEs) play a vital role in the global economy, yet they have been profoundly affected by the disruptions caused by the COVID-19 pandemic. In response, many SMEs have accelerated their digital transformation efforts, using technology as a key driver of innovation to enhance sustainability, competitiveness, and product and service customization. However, there remains limited understanding of how effectively SMEs are adopting digital technologies to support sustainability goals. This study conducts a systematic literature review to explore the intersection of digitalization and sustainability in SMEs. The analysis is structured around three core domains: the technological components of digital transformation, sustainability based on the triple bottom line (economic, environmental, and social dimensions), and SME-specific business characteristics. The review identifies key technological advancements, particularly those aligned with Industry 4.0, that enable SMEs to achieve sustainable development. It also examines the role of corporate strategy, organizational structure and culture, leadership, and workforce capabilities in driving digital and sustainable innovation. The study highlights gaps in the literature and suggests avenues for future research. Overall, the findings offer valuable insights for policymakers and SME stakeholders aiming to align digital transformation strategies with sustainability objectives, contributing meaningfully to the achievement of the Sustainable Development Goals (SDGs).

Keywords: SMEs; Digitalization; Industry 4.0; Sustainability; Technology; Innovation

INTRODUCTION

Small and medium-sized enterprises (SMEs) are widely acknowledged as key drivers of global economic growth (Raihan et al., 2023a). They significantly contribute to job creation and stimulate competitiveness by fostering innovation and entrepreneurial activities (Mago & Modiba, 2022). Representing nearly 90% of businesses globally, SMEs are responsible for more than 50% of employment (World Bank, 2023). However, the outbreak of the COVID-19 pandemic triggered extensive changes in how SMEs operate and adapt to the evolving business environment.

The pandemic has accelerated the adoption of digital transformation, fundamentally reshaping business operations and organizational behavior across borders (Melo et al., 2023). This rapid shift has also challenged SMEs to maintain their competitiveness by digitizing traditional processes (Azevedo & Almeida, 2021). Quinton et al. (2018) assert that businesses can leverage emerging digital technologies by aligning market dynamics, continuous learning, and entrepreneurial orientation to achieve innovation-led growth. Consequently, SMEs are increasingly compelled to integrate innovative and digital production techniques to sustain their competitive position in the long term.

Industry 4.0, characterized by technologies embedded within cyber-physical systems (CPS), plays a pivotal role in reshaping technical and production capabilities, which ultimately contributes to improved business performance. In this transformation, digital technologies do not merely serve operational needs but also support the sustainability agenda. Digital transformation, in this context, becomes both a facilitator and an outcome of efforts toward sustainability. It is essential for firms to develop digital competencies to address the interrelated pillars of sustainability—economic, environmental, and social (Gomez-Trujillo & Gonzalez-Perez, 2021). SMEs can harness digital tools to align their operations with sustainable development goals by supporting circular economy principles and sustainable practices (Telukdarie et al., 2022).

Following the global health crisis, sustainability has become even more critical for SMEs, many of which have struggled with operational disruptions, liquidity issues, and workforce sustainability (Rodrigues et al., 2021). At the same time, businesses are under increasing pressure to integrate environmental considerations into their digital innovation efforts (Feroz et al., 2021). Strategically, sustainable development is now viewed as an approach that enables companies to meet environmental challenges while promoting organizational growth (Lu et al., 2020).

Although various studies have analyzed digitalization in SMEs (Abdirad& Krishnan, 2021; González-Varona et al., 2021; Pfister and Lehmann, 2021), many limit their focus to economic or financial outcomes, often overlooking the broader sustainability implications. Other researchers have explored intersections of Industry 4.0 and sustainability (Rosa et al., 2020; Beier et al., 2020), as well as sustainability in supply chains (Birkel and Müller, 2021). However, a clear research gap persists in evaluating SMEs' performance across digital, economic, social, and environmental dimensions.To address this gap, the present study adopts a systematic literature review methodology to examine how digital transformation influences SMEs' sustainable development. The review covers three main areas: digital technology, sustainability, and SME-specific business characteristics. It offers crucial insights for scholars, practitioners, and policymakers seeking to advance SME digitalization and sustainability. Moreover, the study aligns with key United Nations Sustainable Development Goals (SDGs), including SDGs 1, 2, 3, 5, 8, 9, 10, and 12.

METHODOLOGY

This study employed the systematic literature review (SLR) methodology, as outlined by Raihan and Bijoy (2023), a widely accepted approach known for its credibility and methodological rigor (Benita, 2021). SLRs allow for a structured and transparent exploration of emerging research areas by synthesizing existing literature, identifying research gaps, and proposing future directions. An initial scoping review was conducted to validate the research concept, confirm the uniqueness of the topic, and ensure a sufficient volume of relevant literature on digitalization and sustainability in SMEs was available for comprehensive analysis.

To collect relevant literature, a thorough search was conducted using four prominent academic databases—Google Scholar, Scopus, ScienceDirect, and Web of Science—covering publications from 2000 to 2023. The keyword strategy focused on three primary themes: SMEs, digitalization, and sustainability. Related terms such as "Industry 4.0," "Digital Transformation," "Automation," and "Smart Manufacturing" were also incorporated. Only peer-reviewed research articles were selected to maintain academic reliability. Both qualitative and quantitative studies were included to ensure diverse insights. Citation tracking was then applied to trace subsequent scholarly references to the selected literature. The preliminary search process resulted in the identification of approximately 1,000 relevant publications for further analysis.

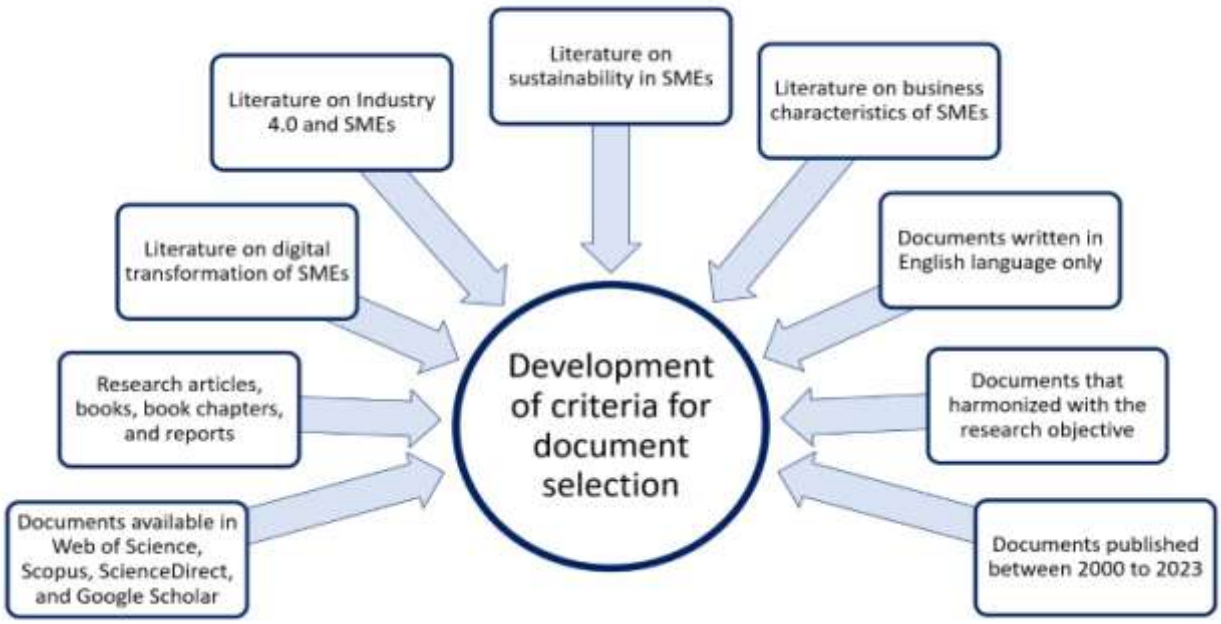

Figure 1. The development of criteria for the selection of documents.

The study used the systematic literature review (SLR) methodology to explore digitalization and sustainability in SMEs. An initial scoping review validated the research concept and identified gaps in existing literature. A thorough search was conducted using four academic databases, covering publications from 2000 to 2023. The keyword strategy focused on three main themes: SMEs, digitalization, and sustainability, with related terms like "Industry 4.0," "Digital Transformation," "Automation," and "Smart Manufacturing." Peer-reviewed research articles were selected, and both qualitative and quantitative studies were included. The preliminary search identified around 1,000 relevant publications for further analysis.

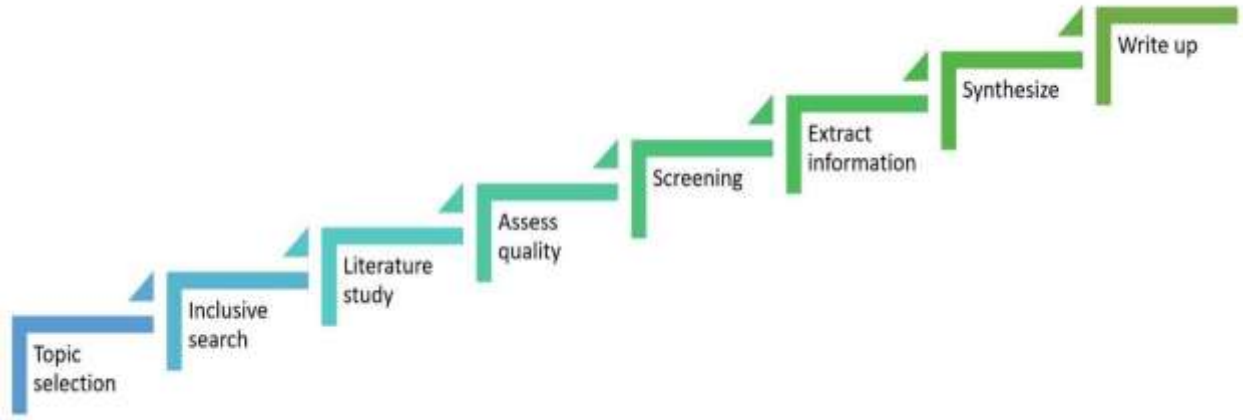

Figure 2. The procedure of systematic review conducted by the study.

RESULTS AND DISCUSSION

Digitalization and technological innovations in SMEs

Digitalization and technological innovations within the framework of Industry 4.0 and sustainability in SMEs are presented in Figure 3. Firms start digital transformation initiatives with a favorable adoption culture and a clear perspective of procedures. SMEs must recognize and grasp digital growth opportunities and implement projectbased learning to stay competitive in turbulent circumstances (North et al., 2019). Mukhtar et al. (2020) showed how IT affects SMEs' sales performance. Others use a basic internet-enabled platform and an eco-sourcing tool based on Model View Control (MVC) architecture for SMEs to allow customers to pick and order vehicle products online (Anthony, 2019). Mekhum (2020) explored how supply chain cultural competence and technology adoption affect Thai SMEs' performance. Both aspects affect performance, but supply chain cultural capabilities are vital to technological adoption, according to the study.

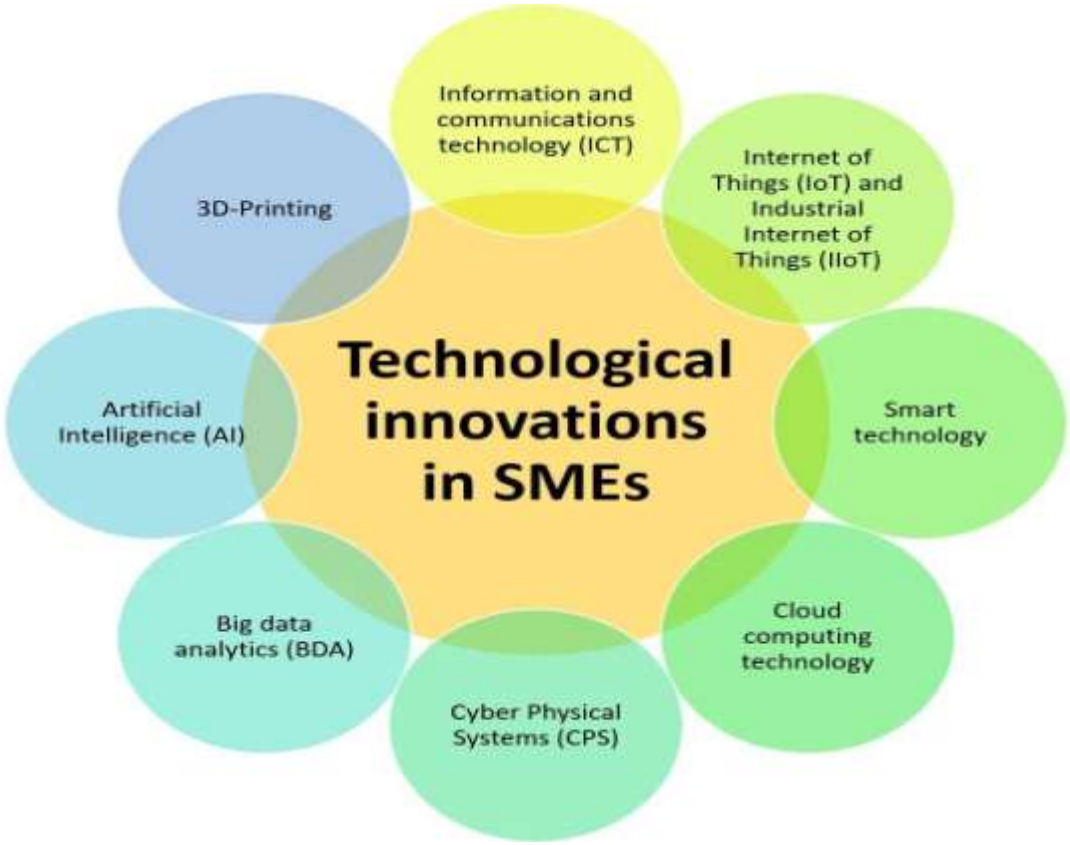

Figure 3. The use of technological innovations within the framework of Industry 4.0 in SMEs.

The IoT and IIoT use embedded sensors in physical items and software and integration to provide real-time monitoring and data exchange over distributed networks. Big data, IoT, and smart factory setups help Thai SMEs deploy IT and perform well (Haseeb et al., 2019). Taiwanese textile SMEs demonstrate how IoT-as-a-service (IoTaaS) creates smart value and sustains businesses (Chen, 2019). Cloud computing and IIoT enable Industry 4.0, which is smart technology (Chonsawat&Sopadang, 2020). Smart Industry 4.0, cloud computing, and CPS enable technology strategies for cross-disciplinary value creation in Taiwanese clothing SMEs (Chen, 2020). Dutta et al. (2020) also noted that IoT, cloud computing, and big data are essential for Indian manufacturing SMEs to digitize. Smart self-monitoring, analysis, and reporting technology uses artificial intelligence, machine learning, and big data analysis to offer appropriate objects and agents cognitive awareness. Automation/robotics adaption in SMEs is studied by Ingaldi and Ulewicz (2019).

Yazdi et al. (2018) demonstrate how SMEs can adopt a sustainable, intelligent smart manufacturing system using robotic systems with sensors. An intelligent material handling system for material distribution uses an agent-based algorithm for control architecture and a time study-based technique to evaluate equipment efficacy. OEE research results optimize processes for sustainable productivity. Overall equipment effectiveness (OEE) helps SMEs reduce overtime, defer capital investments, reduce downtime/idle time, and increase operator performance. In addition, Mittal et al. (2020) emphasized the importance of identifying manufacturing data accessible within the SME, readiness assessment, data-hierarchy phases, smart manufacturing knowledge among SME leadership and employees, development of the SME's smart manufacturing vision, and recognition of smart manufacturing techniques and procedures needed to achieve the firm's vision.

Furthermore, cloud computing lets users store and access information and applications online instead of on a hard disk. Dutta et al. (2020) examined how Indian manufacturing SMEs should use digital technologies for their functional domains. The survey found that Indian SMEs prioritize industrialization—connecting machines and developing data analytics via IoT, Cloud, and Big Data. The survey stressed the need for real-time machine data and performance-based system design and improvement. As reported by Trstenjak et al. (2020), SMEs' company size has a significant impact during development when using digital technology like cloud computing aided by fundamental infrastructure and complex planning methods to outperform traditional firms.

A mechanism is regulated or controlled by computer algorithms in a CPS system. Müller et al. (2018) demonstrated how Industry 4.0 improves supply chain stakeholders by sharing manufacturing data with vendors and consumers. Broad product spectrum through Industry 4.0 adoption (CPS and ICT) and value capture innovations through automated online customer relationship management platforms are prominent elements of the system. Digitalization of manufacturing information addresses data, finance, and human resource shortages that hinder value development. Müller (2019) found that Industry 4.0 adoption affects SMEs.

Big data involves treating, analyzing, and extracting large, diverse, and fast-moving data. Big data analytics (BDA) mediated ‘project performance’ and nine aspects, which include top management, project information management focus on sustainability, buying green, green technology, social obligation, project operations, project difficulty, collaboration and exploratory learning, and achievement of goals (Mangla et al., 2021). In the literature, the technology–organization–environment (TOE) model and resource-based view are combined to model SMEs' BDA adoption (Maroufkhani et al., 2020). To use BDA successfully in manufacturing SMEs, relative benefit, reliability, quantity, risk and uncertainty, trialability, visibility, support from executives, company readiness, competition, external support, and governmental oversight must be considered.

AI allows computers or robots controlled by computers to perform human functions. Basri (2020) explored how AI-assisted social media marketing (AISMM) affects Saudi Arabian startups. Innovative thinking, workplace connection, and lower turnover are AISMM's key benefits. Adoption increases client numbers and profits. Effective business management and SME performance improved using AISMM.

3D printing layers of plastics, composites, or biomaterials to make objects of various shapes, sizes, rigidities, and colors. Coreynen et al. (2017) explored how digitization may promote manufacturer servitization and consumer value-added service. The study used ICT and 3D printing to examine industrial, commercial, and value servitization. Industrial and commercial servitization (based on ICT for customer relationships, web app, and digital ‘marketplace’) offers advising, training, consulting, and online self-service management tools to let clients complete tasks themselves. Value servitization (digital scanner items) helps organizations relieve customers faster.

Sustainability in the SMEs

The environmental impact of manufacturing enterprises has spurred stricter laws to reduce or eliminate manufacturing procedures and other business dangers (Raihan, 2023). Circular economy techniques under Industry 4.0 technologies are needed to address market-driven and environmental issues. For sustainable industrial development, job equity, gender equity, job losses, employee well-being, and growth and quality of life laws are also important. The

sustainability dimension covers economic, social, and environmental issues that affect SMEs and sustainability in general. Figure 4 presents the pillars of sustainability.

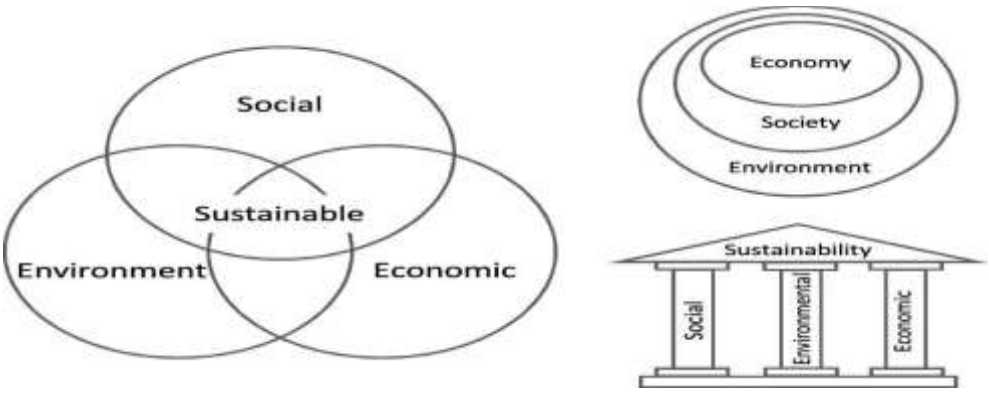

Figure 4. The three pillars of sustainability.

Economic Sustainability

Small firms need innovation and other elements to survive. Technology adoption, product introduction, and service opportunity acquisition lead to corporate sustainability and economic expansion (Begum et al., 2020). Chege et al. (2020) found that entrepreneurial innovativeness positively affects technology innovation and company performance in Kenya. The study suggests new techniques to increase business performance with government support, promote technical externalities in the industry, and construct ICT resource centers to improve SME performance. Technologies enable new business structures and services (Raihan et al. 2023b). Chen (2019) describes textile SMEs' integrated manufacturing, logistics, and marketing methods and value-creation techniques. IoTaaS value chains accomplish the former. Integrating global value chains (GVCs) to co-create value for overseas customers achieves service orientation. Sustainability via value-creation by capturing customer behavior and incorporating them into the business is key. Digitalization enables manufacturing servitization (Coreynen et al., 2017). Servitization and expansion require managers to build digital assets and capabilities for customer-aligned procedures.

Chen et al. (2016) examined how an industry-specific web portal affects e-business organizational performance. Service-oriented portal functions—portal maintenance, B2B, and cloud computing—significantly impact organizational performance. Literature also examined how digital platforms and network capability affect SMEs' financial performance (Cenamor et al., 2019). Digital platform networking capacity improves performance indirectly. Sustainable expansion requires profitably using the platform's capabilities and connecting with the right business orientation. Material, energy, labor, equipment, and fixtures affect a manufacturing firm's sustainability. Case studies in the literature assess sustainability issues for a US SME transitioning from shielded metal arc welding to robotic gas metal arc welding (Epping & Zhang, 2018). Results showed SME benefits from robotic implementation's economic expenses.

Environmental sustainability

SMEs increase greenhouse gas emissions like other enterprises; thus they must take corrective measures. A green company strategy and smart industrial efforts are needed in the current climate. The smart factory concept requires firms to focus on cost calculation, quantitative benefit analysis, and corporate social responsibility (CSR) activities to create a green corporate image and add an environmental dimension (Lu et al., 2020). Chen (2020) used "green manufacturing concepts" to create a strategic plan for integrating textile manufacturers and cultural content producers into GVC. The sustainability assessment process identifies the firm's weaknesses and the best way toward sustainable growth. Tools to quantify product or process environmental effects were investigated by Epping and Zhang (2018).

Life cycle assessment (LCA) to detect and quantify material flows, energy needs, and environmental emissions; public goods tool to display public goods from different farming arrangements in a straightforward, quantitative, and accessible way. Ecological footprint evaluation of methods based on ecological capacity via sustainable process index; carbon footprint calculators-carbon produced by agricultural companies and fixed to soil and biomass on land; multi-criteria instruments, sustainability assessment of food and agriculture systems; global reporting initiative tools. Kassem and Trenz (2020) propose cost-effective, easy, efficient, automated, comprehensive, and simplified sustainability assessment solutions. Czech brewers are testing WEBRIS (Web Information System for Corporate Performance Evaluation and Sustainability Reporting), a basic automated information system. Sustainability value added (SVA) is an effective sustainability evaluation method. Firms must identify economic, environmental, social, and governance elements affecting sustainability (Raihan &Tuspekova, 2022). WEBRIS compares firms' computed SVA to discover weaknesses.

Social sustainability

Llinas and Abad (2020) used Spanish SMEs to demonstrate how high-performance people management techniques boost business efficiency through innovation. People management methods significantly correlated with productivity and innovation, with Industry 4.0 technology as a key facilitator. People management is a top priority for Industry 4.0 firms, according to the survey. Carroll's pyramid approach can improve SMEs' organizational performance and sustainability (Lu et al., 2020). Business success depends on giving stakeholders social, logical, and transitional benefits as the organization transforms. In an age of technology, SMEs must implement technology efficiently and effectively, especially since automation may reduce and replace blue-collar employment. Technology adoption reduces manufacturing jobs by automating boring tasks. Müller and Voigt (2018) advocate training and retraining staff during a company's transformation. This gives workers confidence and well-being. Haseeb et al. (2019) found that firms have IT but seldom implement it, which hurts business performance.

Epping and Zhang (2018) used social life cycle assessment (SLCA) to evaluate the social and socioeconomic implications of robotics adoption. Manufacturing affects earnings and remuneration, safety, personal and technical advancement, and social interaction. Fair wages and on-duty health and safety were emphasized by Epping and Zhang (2018). Through the transition from a 'business-as-usual' plan to a long-term approach for the digitalization of common resources, networking SMEs and other stakeholders (such as academic institutions, rivals, and customers) foster social sustainability. Zoppelletto et al. (2020) examined how a digital transformation strategy (DTS) might improve network organizations' business network commons generation/regeneration. Digital resources drove BNC revitalization, with DTS supporting quality and social responsibility. The study added to the literature on digitalization's social and economic benefits.

Business characteristics of SMEs

An organization's ability to evaluate its internal and external surroundings and respond quickly to market changes defines its sustainability. A firm's aptitude to adapt to these shifts is determined by excellent leadership and management. The organization structure, strategy, and resource base enable customer value delivery. This study addressed company strategy and management, organizational structure, culture, skills and qualifications, and firmspecific leadership as the key business characteristics of SMEs (Figure 5).

With an emphasis on innovation, Industry 4.0 interventions have substantially decreased business model lifecycles. Building a new business model or adapting an existing one to market demands requires innovation. Innovation in firms and the business environment boosts technology activities (Pucihar et al., 2019). To appreciate Industry 4.0 technologies as important facilitators, SMEs require new technology adoption policy measures. SomohanoRodríguez et al. (2020) indicated that SMEs' innovation initiatives positively impact Industry 4.0 digital enablers. The selection and use of the best technology are typically inadequate in SMEs.

Using a maturity-level-based assessment tool is necessary. Rauch et al. (2020) developed and tested a maturity level-based assessment tool on 17 enterprises as well as 42 Industry 4.0 concepts and a plan to help SMEs introduce the most promising ones. Additionally, Jiwangkura et al. (2020) showed multi-dimensional IIoT deployment methodologies with innovative HCI for SMEs in manufacturing. Results show corporations can empower using IIoT. An organization that uses IT, system integration, and automated business processes for gathering data with quality delivery and management would handle competition well (Pomffyová et al., 2017). According to Prause (2019), market uncertainty drives Industry 4.0 technology and process adoption more than internal forces.

Figure 5. The key business characteristics of SMEs.

Several scholars have validated that the effective design of organizational structure and internal processes plays a crucial role in enhancing the implementation of Industry 4.0 and IT adoption in Thailand. Key factors contributing to SMEs' readiness for Industry 4.0 include business models, strategic direction, digitalization, leadership capabilities, internal organizational frameworks, and efficient supply chain management, all of which reinforce organizational resilience. The integration of interdisciplinary communication, along with management innovation and organizational methodologies, fosters an environment supportive of Industry 4.0 concepts.

SMEs that are resilient and can adapt to external changes tend to embed this flexibility within their organizational culture. Mekhum (2020) emphasized that "Organizational culture requires a significant connection with the objectives of an organization since it has a close connection with business performance". Dewi et al. (2020) also found that adaptability strengthens innovation and competitiveness, with innovation serving as a mediator between adaptive capabilities and long-term competitive advantages. However, the mere use of digital tools does not guarantee improved business outcomes unless underpinned by entrepreneurial intent. Innovation, risk appetite, and proactive leadership are essential for thriving in global markets (Raihan et al., 2022).

Chen (2020) highlighted the importance of building trust with business partners to implement value-creation strategies that support Industry 4.0 and help SMEs integrate into the global value chain (GVC). Irimiás and Mitev (2020) conducted a study involving 270 SMEs and large firms in Hungary to explore perspectives on change management, digital transformation, sustainability, and performance. Their findings suggested that while change management positively affects digital maturity and business outcomes, many managers view green practices as cost-ineffective. Misconceptions regarding the strategic benefits of business resource planning often hinder adoption and result in organizational resistance (Jayeola et al., 2020). Maroufkhani et al. (2020) posited that SMEs must cultivate a strong data-driven culture and build resilient digital infrastructure to benefit from Big Data Analytics (BDA). Similarly, Llinas and Abad (2020) proposed that high-performance HR management practices are essential to improve productivity in the Industry 4.0 landscape.

Human resources, qualifications, and skillsets are critical enablers of SME growth and innovation. Sariwulan et al. (2020) investigated SMEs in tourism garment clusters and found that digital literacy, entrepreneurial skills, and economic literacy positively impact business performance by enhancing marketing networks and organizational operations. Bertello et al. (2021) emphasized that BDA capabilities, rather than infrastructure alone, contribute significantly to productivity and international growth. Cenamor et al. (2019) demonstrated that SMEs benefit from digital platforms by leveraging network capabilities to enhance innovation. Chinakidzwa and Phiri (2020) linked SME profitability, market share, and sales growth to effective digital strategy execution. Furthermore, Kulathunga et al. (2020) showed that techno-financial literacy combined with enterprise risk management (ERM) applications leads to operational efficiency, where enhanced financial literacy improves ERM practices.

Utilizing the Technological-Organizational-Environmental (TOE) framework, Alraja et al. (2021) found that effective leadership is key to digital transformation in Omani SMEs. Leaders must craft strategic visions and provide technological support to improve global competitiveness. Martínez-Olvera and Mora-Vargas (2019) developed the CPPR 4.0 model, which views value creation in Industry 4.0 through the customer, product, process, and resource lens. This model also suggests replacing system dynamics with discrete-event simulations to explore cost-revenue optimization in manufacturing, thereby equipping managers with better forecasting and strategic tools.

CONCLUSIONS

The objective of this study is to examine the effects of digital transformation on the sustainable development of SMEs. The systematic literature review approach has facilitated the qualitative synthesis of documents, leading to the discovery of various insights. One notable finding is the significant influence of organizational culture on the adoption of technology and subsequent data management, which serves as the fundamental basis for SMEs to undergo digital transformation. Sustainability projects facilitated by digital technology are made possible by the implementation of inventive solutions. The situation necessitates the implementation of a sustainability assessment in order to determine the necessary parameters and aid managers or leaders in efficiently and effectively transforming SMEs.

The optimization of organizational procedures and structures is crucial as it has a direct influence on the successful application of digital technologies. Furthermore, the choice of technology is contingent upon the digital orientation that is embraced. The prioritization of management requirements over technological sophistication itself becomes crucial in the process of transformation, as it encompasses innovativeness and high performance. It is evident that advanced technologies, including robotics, provide comparable performance to ordinary ICT resources. This observation suggests that creativity, talent, and management play crucial roles alongside technological sophistication. A compilation of potential avenues for future research has been derived from the comprehensive review.

Recommendations and future research directions

This study could be augmented by gathering empirical data via surveys and interviews about the digital transition of SMEs for sustainability. Such studies should delineate technological objectives (short-term, medium-term, and long-term) and develop technology roadmaps to enhance comprehension of how SMEs might use digital technologies to attain sustainability. Digital transformation and Industry 4.0 use IoT, Cyber-Physical Systems, big data, and artificial intelligence/machine learning. Therefore, it is essential to identify the technologies that may most effectively impact SME performance. Additional study is required on the cost-benefit evaluations of digital transformation in SMEs. Comprehending the advantages of digitalization and the potential of certain technologies to enhance competitiveness and productivity is essential. This insight may guide SMEs' digital transformation efforts.

Small and medium-sized enterprises (SMEs) often emphasize economic sustainability; but, to attain true sustainability, they must also confront environmental and social challenges. To attain sustainable growth across all three dimensions, SMEs must comprehend how to mitigate trade-offs across these orientations. The assessment of sustainability must be economical, efficient, automated, thorough, and systematic to advance green manufacturing principles and a go-green strategy. Small and medium-sized enterprises may experience pressure in achieving this objective; thus, supportive measures are essential. Consequently, approaches for assisting SMEs need more investigation. The economic and environmental sustainability of SMEs is widely understood within the context of sustainable development. Research on social sustainability, particularly about how SMEs might enhance social impact in developing countries, is little acknowledged. This critical domain requires more investigation.

Comprehending the integration of technological maturity, organizational structure and processes, leadership competencies, digital proficiency, and knowledge within SME business models is essential. Small and medium-sized enterprises must build innovative business models that reconcile the expenses of digital transformation with the benefits of sustainable growth. Technology-driven innovation using value-creation strategies enables SMEs to engage consumers, suppliers, and stakeholders, hence enhancing market activity. This necessitates stakeholder trust via data exchange with intellectual property protection, although conventional regulations and laws must be examined. These laws and regulations need more investigation on their characteristics and optimal arrangement. Moreover, SMEs need the expertise and understanding to attain sustainable growth. Education and training must facilitate this need and emphasize leadership competencies. Additional study is required to identify support strategies that facilitate the digital transformation of SMEs for sustainable growth.

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