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Evaluating Digital Transformation in SMEs Through Value Creation, Strategic Management, and Sustainability

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Abstract

This study proposes a multidimensional decision-support model for assessing the strategic implications of Digital Transformation (DT) in SMEs under conditions of uncertainty. The study addresses the challenge of measuring the digital impact of DT across value creation, strategic management maturity, and sustainability dimensions. A conceptual framework grounded in strategic management and digital transformation literature is operationalized using the Fuzzy TOPSIS method. A controlled stochastic simulation was conducted to generate a synthetic dataset representing 30 heterogeneous SMEs for computational model-validation purposes. The proposed framework generates three dimension-level performance indices and one aggregated Global Digital Impact Index (GDII). The simulation results illustrate the analytical potential of the framework to support multidimensional digital impact assessment under uncertainty. The study contributes a fuzzy-based evaluation framework capable of integrating value creation, strategic management maturity, and sustainability within a unified digital impact assessment model.

Keywords: Digital Transformation; strategic management; value creation; SMEs; Fuzzy TOPSIS; sustainability

1. Introduction

The digitalization of the economy and social life has profoundly changed nature, dynamics, and methods of organizational functioning, including their competitiveness and value creation. In this respect, the concept of Digital Transformation (DT) encompasses organizational structures, governance, and business models, going beyond the simple adoption of technology (Bharadwaj et al., 2013; Vial, 2019). The current theoretical understanding of DT increasingly considers it to be a multidimensional construct, including the interrelations between technological, organizational, and strategic elements (Verhoef et al., 2021). The DT process assumes particular importance in the context of small and medium-sized enterprises (SMEs), which play a pivotal role in the employment and innovation sphere. However, these firms often face challenges related to the structural aspects of digitalization. These challenges encompass financial constraints, lack of digitalization capabilities, and uncertainty related to the financial returns of DT investments (OECD, 2021; Plekhanov et al., 2023).

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While DT has been associated with several positive outcomes related to organizational performance and sustainability, it has been difficult to evaluate this phenomenon in a comprehensive and integrated manner. The literature has often focused on specific indicators of DT, such as financial performance and technological adoption, which only partially capture the strategic implications of DT (Verhoef et al., 2021). From this perspective, three main dimensions of DT can be identified, including Value Creation, Strategic Management, and Sustainability. The former refers to the contribution of digital technologies to the improvement of value creation, including the optimization of organizational processes, the development of innovative services, and the enhancement of customer experience (Parida et al., 2019). The Strategic Management dimension considers the contribution of digital maturity to the decision-making processes of the organization, including its agility (Sebastian et al., 2020). The dimension of Sustainability considers the contribution of digitalization to the development of sustainability, including the efficiency, monitoring, and transparency of business processes (George et al., 2021).

Despite their critical importance, these dimensions are rarely integrated into a comprehensive evaluation tool capable of dealing with the uncertainty and managerial perceptions involved in the DT process (Schumacher et al., 2016). This is particularly the case in the context of SMEs, where the DT process tends to be evaluated based on qualitative perceptions. Existing DT assessment approaches frequently focus on specific aspects of digitalization, such as technological readiness, digital maturity, financial performance, or sustainability-related outcomes, and therefore provide only a partial view of DT impacts. Many of these approaches rely on deterministic scoring procedures or checklist-based maturity assessments that may not adequately capture ambiguity, linguistic evaluations, and subjective managerial perceptions (Schumacher et al., 2016; Sebastian et al., 2020). Moreover, these approaches often offer limited support for modelling uncertainty associated with qualitative managerial assessments and linguistic evaluations. In such cases, the conventional methods for DT evaluation tend to be ineffective in dealing with the ambiguity and multidimensionality involved in the DT processes (Vial, 2019). Consequently, such methods are less suited to assessing how Digital Transformation simultaneously influences value creation, strategic management maturity, and sustainability within SMEs. To address this gap, this study proposes a fuzzy logic-based decision-support framework to evaluate the multidimensional impact of digital transformation across Value Creation (VC), Strategic Management (SM), and Sustainability (SU). The proposed framework integrates these three dimensions within a unified evaluation model and aggregates their outcomes through a Global Digital Impact Index (GDII). Fuzzy logic provides a suitable basis for modelling imprecise and linguistic information, while Fuzzy TOPSIS offers a robust mechanism for comparing alternatives under uncertainty (Zadeh, 1965; Chen, 2000).

Accordingly, this study addresses the following research question:

How can the impact of Digital Transformation on Value Creation, Strategic Management Maturity, and Sustainability in SMEs be assessed under conditions of uncertainty and subjective managerial evaluation?

The main objective of this study is to develop and computationally validate a structured decision-support framework for assessing the multidimensional impact of Digital Transformation in SMEs. Rather than providing empirical evidence from observed SME populations, the study seeks to evaluate the internal consistency, computational behavior, and analytical applicability of the proposed framework under controlled simulation conditions. The study contributes in three ways. First, it brings together strategic management and sustainability within a single DT assessment framework. Second, it operationalizes these dimensions through fuzzy multi-criteria techniques that accommodate imprecision and linguistic evaluation. Third, it provides a computational model-validation approach based on synthetic benchmarking. From a practical and policy perspective, the framework may provide a basis for future decision-support applications aimed at evaluating digital transition strategies through a multidimensional perspective.

The remaining sections of the paper are structured in the following way. In Section 2, the theoretical background of the study, including digital transformation, value creation, strategic management, sustainability, and fuzzy multi-criteria evaluation, is provided. In Section 3, the conceptual framework and research propositions are developed. Section 4 includes information about the methodological framework of the paper and the use of the Fuzzy TOPSIS model. Section 5 discusses the simulation results. Section 6 addresses the main findings, while Section 7 contains the conclusions of the paper.

2. Theoretical Framework

2.1. Digital Transformation in SMEs

Digital transformation has been identified as a key driver of organizational change. DT goes beyond the mere adoption of digital technologies by also encompassing the integration of these technologies into core organizational activities. This has important implications for processes, structure, and value creation (Bharadwaj et al., 2013; Vial, 2019). In SMEs, DT offers opportunities but also poses important challenges with respect to DT's implementation and evaluation (Appio et al., 2021).

This is particularly relevant in the context of the fact that the majority of enterprises, especially SMEs, play a crucial role in the overall economy, and their digitalization paths are often hindered by their relative lack of financial means, weaker digital competencies, and lower levels of organizational slack compared to larger enterprises (OECD, 2021). As a result, the overall digitalization paths in SMEs are often gradual, with a strong focus on the role of management vision.

Based on previous research, there is evidence that the use of new technologies, including cloud computing, big data analysis, artificial intelligence, and the Internet of Things, can help boost the competitiveness and adaptability of SMEs (Warner & Wäger, 2019). However, the benefits of DT are not automatic. They depend on whether digital technologies are embedded in broader organizational and strategic change processes rather than introduced as isolated technical upgrades. This makes the assessment of digital impact particularly relevant in the SME context (Omrani et al., 2022; Díaz et al., 2024).

2.2. Digital Value Creation

Digital value creation encompasses not only improvements in operational efficiencies and cost reduction but also business model innovation, service innovation in the digital domain, and data-driven customer engagement (Parida et al., 2019; Nambisan et al., 2019). In digitally enabled firms, value co-creation occurs through various dimensions of digital technologies, analytics, and integration of the entire value chain. This has led to a shift in competitive advantage from physical to digital capabilities (Kádárová et al., 2023).

The empirical research findings have confirmed that superior performance outcomes of digital investments are only possible through strategic fit with organizational strategy and the possession of dynamic capabilities (Warner & Wäger, 2019; Verhoef et al., 2021). This finding suggests that value creation does not arise from technology adoption alone. Instead, it is the managerial ability to orchestrate digital assets and the process of organizational transformation that enables value creation through digital investments (Al-Moaid & Almarhdi, 2024).

In the context of SMEs, value creation through digital investment offers opportunities as well as constraints. Digital technologies have opened global market opportunities for SMEs (Li et al., 2018). However, due to the lack of absorptive capacity and managerial capabilities to leverage digital investments, the value created through digital investments in SMEs is often limited. As revealed by Susanti et al. (2023), the financial performance improvements of firms through digital investments are significant only when embedded in innovation-oriented strategies.

In addition to tangible value creation through digital investments in firms, value creation also involves intangible aspects of productivity improvements and revenue expansion (Brynjolfsson & Hitt, 2000). In other words, value created through digital investments involves various dimensions of value. Therefore, it is important to develop a multidimensional approach to value measurement (Parida et al., 2019). Existing studies suggest that Digital Transformation creates value through multiple mechanisms, including operational efficiency improvements, innovation, cost optimization, digital products and services, and enhanced customer experience (Parida et al., 2019; Nambisan et al., 2019; Verhoef et al., 2021).

2.3. Strategic Management and Digital Maturity

Digital transformation fundamentally changes the concept of strategic management by considering digital capabilities an integral part of the organization's fundamental processes rather than secondary supporting activities (Sebastian et al., 2020; Vial, 2019). From a strategic management perspective, digital maturity reflects the organization's ability to incorporate digital capabilities into managerial decision-making, strategic planning, governance processes, and organizational adaptation.

Theoretically, digital maturity could be explored from the resource-based theory and dynamic capabilities approach, which emphasize the value of dynamic digital resources and organizational learning (Teece, 2018; Warner & Wäger, 2019; Bharadwaj et al., 2013). Digital capabilities are considered a source of competitive advantage for organizations when they have the potential to integrate and accumulate digital resources in a dynamic environment. Consequently, digital maturity should not be viewed solely as a technological construct but also as a managerial and organizational capability that supports strategic decision-making and long-term competitiveness.

Cyber security management, digital skills building, and tech interoperability are some of the essential elements of digital strategic maturity (Matarazzo et al., 2021; OECD, 2021). In this regard, SMEs face difficulties with regard to digital maturity elements. In addition, digital infrastructures are heterogeneous for many SMEs (Anwar et al., 2024).

Digital maturity models that are presently available are based on self-assessment scales and checklists (Kraus et al., 2022; Loonam et al., 2018). In this case, digital maturity assessment necessitates the use of structured and flexible approaches that can consider uncertainties while maintaining analytical comparability.

2.4. Sustainability and Digitalization

The interrelation between the concepts of digitalization and sustainability is one of the recent trends in the relevant scientific literature, especially in the context of sustainable development strategies and environmental, social, and governance strategies (George et al., 2021; OECD, 2021). The potential of digital technologies for the improvement of environmental performance is undeniable, especially in terms of increased efficiency in the use of resources, predictive maintenance, and the optimization of logistics (Reinartz et al., 2019).

In the context of the circular economy, the use of digital technologies can facilitate the implementation of the relevant strategies, especially in terms of increased traceability, real-time monitoring, and data transparency (Bressanelli et al., 2018; Kristoffersen et al., 2020). In the case of SMEs, the potential of digitalization lies in the promotion of sustainable production systems and the minimization of waste, especially when the long-term strategic goals of the enterprises are considered (Plekhanov et al., 2023; Akarsu, 2023).

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At the same time, the promotion of the digital transformation of enterprises might have negative environmental effects, especially in terms of increased energy consumption by data centers and the generation of electronic waste (Belkhir & Elmeligi, 2018; George et al., 2021). The effects are referred to as the digital sustainability paradox.

The impact of the digital transformation of enterprises extends beyond the environmental effects, especially in the context of social sustainability, where the promotion of digital inclusion, the upskilling of the workforce, and the promotion of transparency among stakeholders must be considered (Kraus et al., 2022; Verhoef et al., 2021). Furthermore, digital technologies may contribute to broader forms of organizational resilience and adaptive governance by supporting stakeholder participation, knowledge integration, and the development of more sustainable and adaptive organizational systems (Putera et al., 2025). In this context, the assessment of the sustainability effects of the digital transformation must consider the environmental, social, and governance effects, rather than the cost efficiency of the relevant strategies (Rêgo et al., 2022; Gouveia et al., 2024).

2.5. Challenges in Measuring Digital Impact

Although the body of knowledge related to digital transformation is increasing exponentially, the methods of measurement are disorganized and lack methodological consistency (Verhoef et al., 2021; Warner & Wäger, 2019). Many empirical studies have used financial indicators or proxies of information and communication technology (ICT) investments to measure digital transformations at the enterprise level (Kádárová et al., 2023).

Firm-level measurements of digital transformations are also based on various surveys of managerial perceptions, which add subjectivity and ambiguity to the evaluation process (Li et al., 2018; Plekhanov et al., 2023). Although perception-based measurements are valuable for measuring digital transformations in terms of strategic intent, these measurements are inherently imprecise and difficult to standardize for heterogeneous SME populations.

Digital transformations are inherently multidimensional constructs related to enterprise operations, strategy, and sustainability. Classical econometric methods are based on numerical precision and may not be suited for measuring linguistic or qualitative responses to multidimensional constructs such as digital transformations (Vial, 2019; Kraus et al., 2022; Al Mohamed et al., 2023).

2.6. Fuzzy Logic as a Multi-Criteria Evaluation Framework

Fuzzy logic is a formal mathematical framework for modeling vagueness and ambiguity in complex systems, as introduced by Zadeh (1965). Classical binary logic is not applicable to fuzzy logic; fuzzy logic is based on the concept of partial membership values to represent qualitative judgments quantitatively.

In the context of strategic and socio-economic modelling, where uncertainty plays an important role, fuzzy multi-criteria decision-making (MCDM) methods have significant advantages over the conventional regression analysis approach (Zimmermann, 2001; Kahraman et al., 2015). The fuzzy approach allows for the consideration of linguistic variables such as "high digital maturity" or "moderate sustainability impact."

Fuzzy multi-criteria decision-making (MCDM) techniques have established the robustness of Fuzzy TOPSIS for ranking alternatives under uncertain conditions (Chen, 2000; Toklu, 2020). The approach calculates the relative distance of alternatives from the ideal and anti-ideal solutions, thus facilitating the multidimensional evaluation of alternatives without the need for any statistical assumption. Recent studies have confirmed the suitability of Fuzzy TOPSIS for the evaluation of digital maturity, strategic analysis, and sustainability (Qiao et al., 2024).

The ability of Fuzzy TOPSIS to transform managerial evaluations into fuzzy numbers makes it particularly relevant for the SME sector, where managerial evaluation plays an important role in strategic analysis.

Fuzzy logic, therefore, provides theoretical and methodological grounds for the development of the multidimensional Digital Impact Index, considering the factors of value creation, strategic maturity, and sustainability, all in the presence of uncertainty (Gouveia et al., 2025).

2.7. Research Gap

Despite the increasing number of publications on DT, there remain certain theoretical and methodological gaps in measuring the organizational impact of DT, specifically for small and medium-sized enterprises (SMEs). Although various studies have attempted to analyze digitalization from different aspects such as technological, strategic, organizational, and performance aspects, the integration of these aspects into a holistic and multidimensional framework for measuring DT is still at an emerging stage (Vial, 2019; Verhoef et al., 2021). Several gaps remain regarding conceptual integration, measurement design, uncertainty modelling, and validation approaches in the assessment of DT impacts in SMEs.

Firstly, a conceptual integration gap remains in DT literature. Most of the existing literature on DT treats value creation, strategic management, and sustainability as distinct concepts rather than as interconnected aspects of DT. This creates limitations in the holistic and multidimensional analysis of DT as a complex process in which efficiency, strategic management, and sustainability evolve as interconnected aspects of DT (George et al., 2021; Kraus et al., 2022; Matarazzo et al., 2021).

Secondly, a measurement design and uncertainty-modelling gap can be identified in the Digital Transformation assessment literature. While several investigations have explored the topic of DT by using surveys, maturity models, or econometric analysis (Li et al., 2018; Omrani et al., 2022; Plekhanov et al., 2023), very little attention has been paid to developing multidimensional models which would allow assessing not only the strategic and organizational benefits but also sustainability implications under conditions of uncertainty. The majority of the empirical literature on DT is based on econometric methods or perception-based surveys, which are based on the assumption of precision and accuracy between digital investments and performance outcomes However, DT is a complex and dynamic process influenced by various factors of judgment and uncertainty, and for SMEs, DT is often based on qualitative and linguistic evaluations of digital maturity (Li et al., 2018; Omrani et al., 2022).

Thirdly, a multidimensional assessment gap remains regarding the integration of sustainability within DT evaluation frameworks. Sustainability tends to be perceived as the secondary outcome rather than an essential component of the effectiveness of DT efforts. Although digitalization may positively affect the energy efficiency of organizations, the adoption of circular economy practices, transparency, etc., the issue has been analyzed separately from other aspects of DT, which limits the possibility of exploring its impact on the sustainability of companies and the economy (George et al., 2021; OECD, 2021; Rao & Shukla, 2023).

Finally, an analytical validation gap remains in many DT maturity assessment approaches. Digitalization maturity models are largely based on categorical models of digitalization maturity or checklist-based diagnostic tools with limited analytical depth and comparability (Sebastian et al., 2020; Warner & Wäger, 2019). In this context, the need for an approach that could help convert managerial decisions into measurable performance metrics emerged, taking into consideration uncertainty.

Although literature provides important contributions regarding digital transformation, value creation, strategic management, sustainability, and fuzzy multi-criteria evaluation, these topics are frequently examined from distinct analytical perspectives. As digital transformation assessment approaches vary considerably in their objectives and analytical focus, direct comparisons are challenging. Table 1 therefore presents representative studies from related research streams and positions the proposed framework within the broader Digital Transformation assessment literature.

Table 1. Comparison of representative studies related to Digital Transformation assessment (Source: Author's own elaboration).

Reference	Main Focus	VC	SM	SU	Fuzzy MCDM
Parida et al. (2019)	Digital value creation	✓	Partial	✗	✗
Matarazzo et al. (2021)	Customer value creation	✓	Partial	✗	✗
Sebastian et al. (2020)	Digital strategy and governance	✗	✓	✗	✗
Schumacher et al. (2016)	Digital maturity	✗	Partial	✗	✗
George et al. (2021)	Digital sustainability	✗	Partial	✓	✗
Melo et al. (2023)	Sustainable digital transformation	Partial	Partial	✓	✗
Chen (2000); Kahraman et al. (2015)	Fuzzy MCDM methods	✗	✗	✗	✓
Present study	Integrated DT impact assessment	✓	✓	✓	✓

As illustrated in Table 1, several previous studies have primarily focused on some aspects of digital transformation such as value creation, strategic management, sustainability, and decision support techniques. While these efforts have certainly added much to the body of knowledge in digital transformation, there has been less attention directed towards an approach for evaluating digital transformation that would be able to simultaneously consider these aspects under uncertainty.

The novelty of the proposed framework does not stem from the individual dimensions considered or from the use of Fuzzy TOPSIS as an isolated decision-support technique. Rather, it resides in the integration of Value Creation, Strategic Management Maturity, and Sustainability within a unified Digital Transformation assessment framework, the development of the aggregated Global Digital Impact Index (GDII), and the computational validation of the framework under uncertainty. Together, these elements provide a multidimensional perspective that is not commonly found in existing Digital Transformation assessment approaches.

In summary, the literature reveals four interrelated gaps. First, a conceptual integration gap persists regarding the joint consideration of value creation, strategic management maturity, and sustainability as interconnected outcomes of Digital Transformation. Second, a measurement design gap remains in the development of multidimensional DT assessment frameworks. Third, an uncertainty-modelling gap arises from the difficulty of incorporating qualitative managerial judgments and linguistic evaluations into structured assessment procedures. Finally, an analytical validation gap remains due to the limited comparability and analytical depth of many existing DT maturity assessment approaches. The present study seeks to address these gaps through the development and computational validation of a multidimensional fuzzy decision-support framework for assessing the impact of Digital Transformation in SMEs.

3. Conceptual Model Development

3.1. Conceptual Model of Digital Impact

Building on Section 2, this study proposes a multidimensional model, wherein Digital Transformation is related to three main SME performance dimensions: Value Creation (VC), Strategic Management Maturity (SM), and Sustainability (SU).

DT is considered a structural driver affecting organizational performance on multiple fronts: operations, strategy, and sustainability. These are not considered separate outcomes but rather integrated components of a new multidimensional model: Digital Impact. The model reflects the systemic nature of DT, wherein improvements in operations, strategy, and sustainability are simultaneously affected by DT depth and organizational readiness, as argued by Vial (2019) and Verhoef et al. (2021).

Figure 1 distinguishes between the conceptual construct (Digital Transformation), the three evaluation dimensions (Value Creation, Strategic Management Maturity, and Sustainability), the associated evaluation criteria used to operationalize each dimension, and the final Global Digital Impact Index (GDII). This structure provides the conceptual basis for the multidimensional assessment framework developed in the subsequent sections.

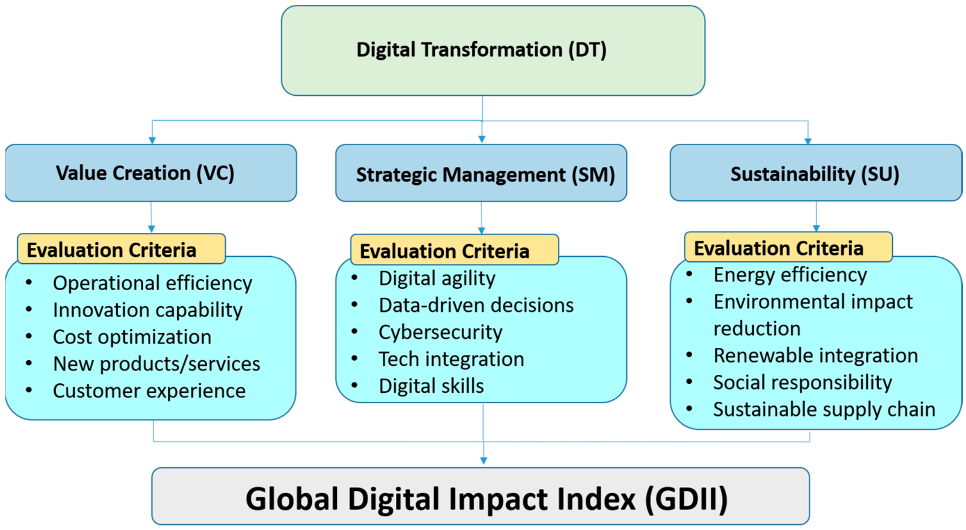

Figure 1. Multidimensional Digital Transformation impact model for SMEs (Author's own creation).

3.2. Operationalization of Dimensions

Each element of the model is defined by five criteria based on the existing research on digital transformation, strategic management, and sustainable development of SMEs. The list of criteria was formed based on the systematic analysis of the scholarly articles on Digital Transformation, Strategic Management, and Sustainability in SMEs (Parida et al., 2019; Sebastian et al., 2020; George et al., 2021; Verhoef et al., 2021; Kraus et al., 2022) where focus was on those elements that appear frequently and can be estimated through managerial evaluations. The final selection sought to balance theoretical coverage and practical applicability while maintaining symmetry across the three dimensions, following a literature-driven rather than expert-driven criterion selection process. The retained criteria reflect key aspects of Digital Transformation that are consistently discussed in the literature and that exhibit a clear conceptual association with the corresponding dimension of the framework. Particular attention was given to selecting criteria that could be reasonably assessed through managerial judgments expressed as linguistic evaluations, thereby ensuring compatibility with the fuzzy decision-making approach adopted in this study. In addition, the selection process aimed to preserve a balanced representation of Value Creation, Strategic Management Maturity, and Sustainability by assigning an equal number of criteria to each dimension, supporting comparability, consistency, and aggregation within the proposed multidimensional evaluation framework.

The Value Creation (VC) dimension captures the operational and market effects of digital transformation in terms of efficiency benefits, innovation potential, cost optimization, development of digital products or services, and customer experience (Matarazzo et al., 2021; Qiao et al., 2024; Alamäki & Korpela, 2021). These elements represent different sources of competitive advantage from a tangible and intangible perspective (Parida et al., 2019; Kraus et al., 2022).

The Strategic Management Maturity (SM) dimension measures the firm's ability to incorporate digital technologies into its governance, planning, and decision-making processes (Gouveia et al., 2025). Beyond technological adoption, strategic management maturity also depends on organizational capabilities, governance quality, managerial behavior, and the ability to align digital initiatives with organizational objectives (Saputra et al., 2026). The factors include digital agility, data-driven decision-making, cybersecurity, the technological integration of the business, and the development of digital skills, thus capturing the essential attributes of the firm's adaptability (Sebastian et al., 2020; Loonam et al., 2018).

The Sustainability (SU) dimension measures the environmental and social consequences of digital transformation (Melo et al., 2023). The factors include the achievement of higher energy efficiency, the reduction in environmental impact, the development of renewable energy sources, the encouragement of corporate social responsibility, and the development of the supply chain using digital technologies (George et al., 2021; OECD, 2021).

All the three dimensions were selected collectively in that they represent the different manifestations of digital transformation in relation to their different levels of organizational impact. The Value Creation represents the economic results of the digitization process; Strategic Management Maturity refers to the managerial capacities necessary for the integration of digitization technology into the business process; while the third dimension, Sustainability, refers to the sustainability impacts of digitization. Collectively, the dimensions represent the economic, strategic, and sustainability dimensions of the impacts of digitization. The operationalization of each dimension using five criteria ensures consistency while maintaining flexibility.

3.3. Multidimensional Structure of Digital Impact

The proposed framework assumes a multidimensional structure of Digital Transformation as a strategic concept whose impact is diffused across different organizational dimensions. DT is considered to produce a systemic effect that simultaneously affects value creation, strategic management capabilities, and sustainability performance.

This approach is also consistent with the concept of digital strategy, which focuses on the integrated nature of organizational/technological strategy and digital transformation (Vial, 2019; Verhoef et al., 2021, Bharadwaj et al., 2013). In the case of SMEs, whose organizational structures are often more fluid, DT is assumed to produce cross-functional effects. For example, investments in digital analytics are assumed to simultaneously affect value creation, strategic management capabilities, and sustainability performance.

In line with these premises, the three dimensions of DT are analytically distinct but structurally related: Value Creation (VC), Strategic Management Maturity (SM), and Sustainability (SU). Although each of these dimensions captures a specific aspect of DT impact, their simultaneous evaluation provides a more complete picture of DT outcomes.

To capture the holistic nature of DT impact, the proposed framework introduces the concept of the Global Digital Impact Index (GDII), which aggregates the partial indices of DT impact obtained for each dimension: IVC, ISM, and ISU. The proposed index provides

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a holistic measure of DT impact, considering the simultaneous effect of value creation, strategic management capabilities, and sustainability performance.

By considering a multidimensional structure of DT impact, the proposed framework overcomes a limitation of previous research that often focused on isolated or technology-based indicators of DT impact. The proposed GDII provides a proxy measure of DT performance in conditions of uncertainty.

3.4. Methodological Rationale for a Fuzzy MCDM Approach

The multidimensional and perceptual nature of the digital transformation in SMEs generates ambiguity and subjectivity, especially when dealing with relevant factors that cannot be measured using objective metrics.

Quantitative methods' capacity for dealing with such ambiguity is limited, especially when dealing with interdependent dimensions defined linguistically. In this regard, fuzzy logic offers a comprehensive approach to dealing with ambiguity, especially when it comes to converting qualitative assessments into structured numerical representations (Zadeh, 1965; Zimmermann, 2001; Kahraman et al., 2015).

In addition, the use of MCDM methods is relevant in situations where the evaluation criteria are numerous, varied, or even contradictory. Among the MCDM methods, Fuzzy TOPSIS allows for the ranking of alternatives based on their relative distances from ideal and anti-ideal solutions, including the ambiguity associated with qualitative assessments (Chen, 2000; Kahraman et al., 2015; Al Mohamed et al., 2023; Sahoo et al., 2024). This makes it particularly relevant for the SME sector, where decision-making often relies on incomplete or experiential knowledge.

The combination of fuzzy logic and the TOPSIS method ensures methodological consistency with the model's multidimensional nature, especially when dealing with the conversion of qualitative assessments into relevant performance indices.

3.5. Analytical Propositions

To operationalize the research question within the proposed multidimensional framework, the present study formulates a set of analytical propositions representing the expected structural relationships between Digital Transformation and SME performance outcomes. While not formulated as statistical hypotheses in the empirical sense, the propositions outlined in the following section represent theoretically derived structural expectations whose logical consistency is assessed through the computational model. Accordingly, the propositions presented in this study should be interpreted as theoretical design principles and modelling assumptions that guide the construction of the proposed framework rather than as empirically validated causal relationships.

Proposition 1 (P1). *Digital Transformation is structurally associated with improvements in Value Creation mechanisms within SMEs.*

The proposition assumes that digital technologies improve operational efficiency, promote innovation, and enhance customer engagement processes (Ratten & Jones, 2020). With the increase in digital integration, firms should increasingly move towards an "ideal" value-creation state in the multidimensional evaluation space (Bharadwaj et al., 2013; Parida et al., 2019; Qiao et al., 2024).

Proposition 2 (P2). *Digital Transformation is structurally associated with higher levels of Strategic Management Maturity.*

Digital transformation influences governance structures, decision-making processes, and the development of firms' competencies. With the increase in digital integration in firms, the expected structural relationships include enhanced agility, more robust decision-making using data, and more effective technological alignment (Sebastian et al., 2020; Warner & Wäger, 2019; Rêgo et al., 2022).

Proposition 3 (P3). *Digital Transformation is structurally associated with enhanced Sustainability performance when strategically aligned.*

While the positive impact of digital transformation on sustainability is not assured, the alignment of digital strategy is expected to enhance improvements in energy efficiency, environmental monitoring, and social responsibility (George et al., 2021; Kraus et al., 2022).

Proposition 4 (P4). *A multidimensional aggregated digital impact index is more comprehensive in its representation of the impact of Digital Transformation compared to single-dimensional measures.*

Because of the systemic nature of digital transformation, an integrative index of digital transformation effects, both positive and negative, is expected to more accurately capture the overall digital impact compared to any single dimension of performance (Vial, 2019; Verhoef et al., 2021).

The propositions outlined previously establish the structural logic for the model-based approach outlined in the subsequent section. Instead of testing for causality through regression-based approaches, the present study tests for the consistency of the computational behavior of the model with the theoretically derived expectations.

4. Methodology

4.1. Research Design

This study adopts a quantitative modelling approach to assess the strategic impact of Digital Transformation in SMEs. The proposed framework integrates three dimensions—Value Creation, Strategic Management Maturity, and Sustainability—capturing complementary aspects of organizational performance.

Given the exploratory nature of the study and the absence of structured datasets capturing the multidimensional effects of DT in SMEs, a computational validation strategy was employed. Specifically, a controlled stochastic simulation was used to generate a synthetic dataset representing 30 heterogeneous SMEs operating across different sectors. The simulated dataset was generated using probabilistic distributions designed to approximate realistic managerial assessments. Instead of using random numbers, the response distributions were centered around medium to high levels of digital adoption, considering that empirical evidence suggests that SMEs exhibit heterogeneous, yet increasingly evolving, levels of digital maturity (Plekhanov et al., 2023; Verhoef et al., 2021).

This approach enables systematic evaluation of the model's structural behavior under controlled conditions, ensuring internal consistency and comparability across alternatives. At the same time, it mitigates limitations associated with small or incomplete empirical samples and allows the assessment of the model's ability to generate stable rankings and multidimensional performance indices under conditions of uncertainty and subjective evaluation.

Synthetic Dataset Generation and Reproducibility Procedure

To evaluate the computational behavior of the proposed framework, a synthetic dataset representing 30 heterogeneous SMEs was generated through a controlled stochastic simulation procedure. The use of simulated data is consistent with the exploratory nature of the study, whose objective is not to provide empirical evidence regarding the digital transformation performance of real SMEs, but rather to assess the internal consistency, computational behavior, and analytical applicability of the proposed multidimensional evaluation framework. The selection of 30 simulated SMEs was intended to provide sufficient heterogeneity to evaluate the framework's ability to generate differentiated performance profiles and rankings while maintaining analytical tractability and transparency of the simulation process. Since the objective is computational validation rather than statistical inference, the number of alternatives should not be interpreted as a representative sample of any SME population.

The linguistic assessments were generated for the fifteen evaluation criteria associated with the three dimensions of the framework, which are presented in the following section. Each evaluation was expressed using one of five linguistic categories ranging from Very Low (VL) to Very High (VH), which were subsequently converted into Triangular Fuzzy Numbers (TFNs) and processed using the Fuzzy TOPSIS methodology.

Rather than adopting a uniform random assignment, the simulation employed predefined probability distributions to generate linguistic evaluations. This approach was designed to create a controlled validation environment in which SMEs exhibit heterogeneous performance profiles while maintaining an overall tendency towards moderate and relatively advanced levels of digital transformation. Such an assumption enables the framework to be evaluated under conditions where meaningful differentiation among alternatives can emerge.

To preserve heterogeneity across dimensions, distinct probability distributions were specified for Value Creation, Strategic Management Maturity, and Sustainability. In particular, the Sustainability dimension was modelled using a slightly more conservative distribution, reflecting the possibility that sustainability-related digital initiatives may evolve at a slower pace than operational or strategic digitalization efforts. The probability structure favored Medium, High, and Very High evaluations while preserving variability across SMEs and criteria. These distributions should not be interpreted as representative of any specific SME population, but rather as simulation parameters adopted for model-validation purposes.

For each SME–criterion combination, a random value was generated and associated with a linguistic category according to the probability distribution defined for the corresponding dimension (Appendix A). This procedure ensured variability among alternatives while maintaining consistency with the predefined simulation scenario.

To enhance the reproducibility of the simulation procedure, a fixed random seed was adopted during dataset generation, ensuring that the synthetic dataset and the resulting rankings can be replicated under identical simulation settings (Appendix A).

It is important to emphasize that the simulated SMEs do not correspond to real firms and were not assigned to specific industrial sectors. Therefore, the dataset should be viewed as a computational benchmarking environment designed to evaluate the behavior of the proposed framework under controlled conditions. Future studies should extend the validation process using empirical SME data, sector-specific analyses, expert-based assessment procedures, and alternative weighting schemes.

4.2. Evaluation Framework

The evaluation framework operationalizes the conceptual model by applying fifteen evaluation criteria across three dimensions: Value Creation (VC), Strategic Management Maturity (SM), and Sustainability (SU). Each SME is evaluated using these criteria through linguistic assessments, which are subsequently incorporated into the fuzzy decision matrix. This structure enables a systematic comparison of alternatives across multiple dimensions under conditions of uncertainty. Table 2 presents the set of evaluation criteria used in the model. To capture managerial evaluations under conditions of uncertainty, the assessment of each criterion is performed using a five-point linguistic scale ranging from Very Low (VL) to Very High (VH). As will be shown later, these linguistic assessments are subsequently converted into Triangular Fuzzy Numbers (TFNs), allowing qualitative perceptions to be incorporated into the fuzzy multi-criteria decision-making model used in the analysis.

Table 2. Evaluation criteria for assessing the impact of digital transformation in SMEs (Source: Author's own elaboration).

Dimension	Code	Evaluation Criterion
Value Creation	VC1	Improvement in operational efficiency through digital technologies
Value Creation	VC2	Digital-enabled innovation capability
Value Creation	VC3	Cost optimization through digital integration
Value Creation	VC4	Development of new digital products or services
Value Creation	VC5	Enhancement of customer experience through digital channels
Strategic Management	SM1	Digital agility in responding to market changes
Strategic Management	SM2	Data-driven decision-making processes
Strategic Management	SM3	Cybersecurity governance and digital risk management
Strategic Management	SM4	Integration of digital technologies across organizational processes
Strategic Management	SM5	Development of digital skills and employee capabilities
Sustainability	SU1	Improvement of energy efficiency through digital monitoring systems
Sustainability	SU2	Reduction in environmental impact through digital technologies
Sustainability	SU3	Integration of renewable energy solutions supported by digital infrastructure
Sustainability	SU4	Digital support for corporate social responsibility practices
Sustainability	SU5	Digitally enabled sustainable supply chain management

4.3. Fuzzy TOPSIS Procedure

The evaluation methodology adopted in the present case adopts the concept of the Fuzzy Technique for Order Preference by Similarity to the Ideal Solution (Fuzzy TOPSIS). It allows for the inclusion of linguistically expressed opinions in the context of structured decision-making amid the element of uncertainty (Nădăban et al., 2016; Palczewski & Sałabun, 2019). The application of Fuzzy TOPSIS in the present analysis has been used to evaluate the performance of the SMEs in relation to VC, SM, and SU dimensions. Each SME will be treated as an alternative, to be evaluated on the criteria established in Section 4.2.

Linguistic assessments are converted into triangular fuzzy numbers (TFNs) (1) and organized into a fuzzy decision matrix (2). All evaluation criteria listed in Table 2 are treated as benefit criteria, meaning that higher values indicate more desirable Digital Transformation outcomes. This assumption is consistent with the wording of the criteria, which are formulated as positive contributions of Digital Transformation. For example, VC1 refers to improvement in operational efficiency, SM2 to stronger data-driven decision-making processes, SU1 to improvement of energy efficiency through digital monitoring systems, and SU2 to reduce environmental impact through digital technologies. Accordingly, higher linguistic evaluations for these criteria represent more favorable outcomes and are therefore modelled as benefit-oriented criteria. The matrix is then normalized (3) and weighted (4), after which the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) are determined. The distances to these reference solutions are computed (5–6), followed by the calculation of the relative closeness coefficient (7). This coefficient represents the relative performance of each SME, where higher values indicate closer proximity to the ideal solution. The sequence of equations is presented in Table 3.

Table 3. Fuzzy TOPSIS method: equations summary (Source: Author's own elaboration).

No.	Step	Expression
(1)	Triangular Fuzzy Number (TFN) representation	$\widetilde{x} = (l, m, u)$
(2)	Construction of the Fuzzy Decision Matrix	$\widetilde{X} = \left[\widetilde{x}_{ij}\right]$
(3)	Normalization of the Decision Matrix (Benefit Criteria)	$\widetilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{m_j^*}, \frac{u_{ij}}{l_j^*}\right)$
(4)	Weighted Normalized Fuzzy Matrix	$\widetilde{v}_{ij} = \widetilde{r}_{ij} \times W_j$
(5)	Distance to Fuzzy Positive Ideal Solution (FPIS)	$D_i^+ = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^+\right)$
(6)	Distance to Fuzzy Negative-Ideal Solution (FNIS)	$D_i^- = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^-\right)$
(7)	Relative Closeness Coefficient	$C_i^- = \frac{D_i^-}{D_i^+ + D_i^-}$

After computing the relative closeness coefficients, dimension-level performance indices are obtained for each SME: the Value Creation Index (IVC), the Strategic Management Maturity Index (ISM), and the Sustainability Index (ISU). These indices are aggregated to compute the Global Digital Impact Index (GDII), which provides an integrated measure of digital transformation performance. Assuming equal weights, the GDII reflects the combined contribution of the three dimensions and enables the ranking of SMEs according to their proximity to the ideal solution. The GDII is computed as the arithmetic mean of the three dimension-level indices (IVC, ISM, and ISU). Equal weighting was adopted as a neutral baseline assumption because no empirical or theoretical evidence was available to justify assigning greater importance to any specific dimension. This choice is consistent with the computational validation objective of the study and facilitates the interpretation of the aggregated index.

To evaluate the computational behavior of the model, a controlled stochastic simulation was conducted using a synthetic dataset of 30 SMEs. The evaluations were generated using probabilistic distributions centered on moderate to high levels of digital maturity. Linguistic evaluations were captured using a five-level scale and converted into triangular fuzzy numbers (TFNs). The corresponding scale is presented in Table 4.

Table 4. Linguistic scale and corresponding triangular fuzzy numbers (Source: Author's own elaboration).

Linguistic Term	Triangular Fuzzy Number (TFN)
Very Low (VL)	(0.01, 0.01, 0.25)
Low (L)	(0.01, 0.25, 0.50)
Medium (M)	(0.25, 0.50, 0.75)
High (H)	(0.50, 0.75, 1.00)
Very High (VH)	(0.75, 1.00, 1.00)

The conversion of linguistic assessments into TFNs enables qualitative managerial perceptions to be incorporated into the evaluation process while preserving uncertainty and imprecision. These fuzzy representations are subsequently used in the Fuzzy TOPSIS calculations and directly influence the distances to the ideal and anti-ideal solutions, thereby affecting the resulting dimension-level indices and final GDII rankings.

For illustration purposes, Figure 2 presents the triangular fuzzy representation of two linguistic evaluations (“Medium” and “High”), highlighting the overlap between adjacent fuzzy sets.

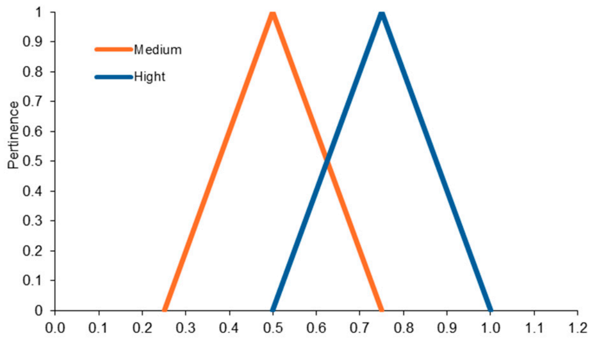

Figure 2. Triangular fuzzy representation of adjacent linguistic evaluations (“Medium” and “High”) used in the model.

To evaluate the robustness of the proposed framework with respect to weighting assumptions, a sensitivity analysis was conducted using alternative dimension-level weighting schemes. Three additional scenarios were considered, respectively prioritizing Value Creation, Strategic Management Maturity, and Sustainability. The resulting GDII values and rankings were compared with the baseline equal-weight scenario using rank correlation and ranking stability measures.

5. Results

This section presents the computational behavior of the proposed framework using a controlled simulation environment. As the objective of the study is to evaluate the internal consistency, computational behavior, and analytical applicability of the model rather than analyze empirical SME data, a synthetic dataset was employed.

The simulation enables the implementation of the Fuzzy TOPSIS procedure and the computation of the dimension-level indices, namely the Value Creation Index (IVC), Strategic Management Maturity Index (ISM), and Sustainability Index (ISU), as well as the Global Digital Impact Index (GDII). The results illustrate how the framework behaves under conditions of uncertainty and linguistic evaluation while providing a structured mechanism for ranking alternatives according to their proximity to the ideal solution.

In addition to presenting the baseline results obtained under equal weighting assumptions, this section also examines the robustness of the framework through a sensitivity analysis based on alternative dimension-level weighting scenarios. Together, these analyses provide insight into both the computational performance and the stability of the proposed decision-support framework.

5.1. Simulated Dataset

A synthetic dataset representing 30 heterogeneous SMEs was generated, with each firm evaluated across the fifteen criteria defined in Section 4.2.

The dataset was generated through the controlled stochastic simulation procedure described in “Section Synthetic Dataset Generation and Reproducibility Procedure” and subsequently used as the input for the Fuzzy TOPSIS analysis. Linguistic assessments were converted into triangular fuzzy numbers according to the scale presented in Table 4, forming the fuzzy decision matrix used in the analysis. For transparency and reproducibility purposes, the generated linguistic evaluation matrix is provided in Appendix A.

The resulting dataset contains heterogeneous performance profiles across the three evaluation dimensions, providing a suitable environment for assessing the ability of the proposed framework to generate differentiated performance scores and rankings under conditions of uncertainty and linguistic evaluation.

This dataset serves as the input for the Fuzzy TOPSIS procedure, enabling the computation of the performance indices for each SME.

5.2. Dimension-Level Performance Indices

The results obtained by applying the Fuzzy TOPSIS methodology provide three performance indices for each SME: the Value Creation Index (IVC), the Strategic Management Maturity Index (ISM), and the Sustainability Index (ISU). These performance indices are relative closeness coefficients and vary in the range [0, 1], with increasing values indicating improved performance in each dimension.

The results obtained illustrate heterogeneous performance levels among the simulated SMEs. This simulation suggests that the impact of digital transformation on the capabilities of each organization may be reflected differently across dimensions within the controlled simulation environment. In other words, it is possible that an SME receives higher scores in one dimension while exhibiting lower scores in another dimension.

This approach allows for a more comprehensive and analytically robust analysis of the impact of digital transformation compared to the use of a single aggregated index. In what follows, Table 5 presents the dimension-level performance indices of the simulated SMEs.

To provide a clearer and more comprehensive overview of the results, Figure 3 illustrates the distribution and variability of performance across the three dimensions, highlighting differences in central tendency and dispersion among SMEs.

The dimension-level indices, as depicted in Table 5, illustrate the relative performance of each SME along the three dimensions. The results indicate heterogeneous performance profiles among the simulated firms. Some SMEs have achieved higher scores in the Value Creation dimension, which within the simulation environment may be associated with operational efficiency, innovation, and customer-centric digital initiatives. Conversely, the results for the Strategic Management Maturity dimension indicate variability across the SMEs, illustrating differences in the simulated evolution of governance structures and digital capabilities.

The Sustainability dimension presents greater variability and, in several cases, lower scores, which may suggest within the simulation scenario that sustainability outcomes depend not only on the adoption of digital technologies but also on strategic and organizational factors.

The heterogeneous performance profiles observed across the three dimensions illustrate the multidimensional nature of Digital Transformation. Within the simulation environment, some SMEs achieve stronger performance in Value Creation while exhibiting comparatively lower Sustainability scores, suggesting that digital initiatives may generate operational and strategic benefits without necessarily producing equivalent sustainability outcomes. Such differentiated profiles demonstrate the ability of the proposed framework to identify potential strengths and weaknesses across dimensions rather than relying on a single aggregated measure.

The results illustrate the need for a multidimensional approach, as the performance of firms may vary across the dimensions. The indices will now be used to compute the Global Digital Impact Index (GDII), which is discussed in the following subsection.

Table 5. Dimension-level performance indices for simulated SMEs (Source: Author's own elaboration).

SME	IVC	ISM	ISU
SME1	0.464	0.565	0.551
SME2	0.312	0.208	0.472
SME3	0.540	0.809	0.602
SME4	0.524	0.481	0.663
SME5	0.465	0.692	0.536
SME6	0.524	0.622	0.602
SME7	0.736	0.353	0.422
SME8	0.540	0.496	0.726
SME9	0.674	0.349	0.424
SME10	0.809	0.749	0.602
SME11	0.748	0.760	0.778
SME12	0.674	0.496	0.613
SME13	0.736	0.692	0.714
SME14	0.390	0.551	0.486
SME15	0.748	0.634	0.360
SME16	0.525	0.819	0.540
SME17	0.586	0.680	0.599
SME18	0.722	0.691	0.602
SME19	0.600	0.494	0.612
SME20	1.000	0.605	0.425
SME21	0.587	0.692	0.674
SME22	0.449	0.565	0.540
SME23	0.798	0.608	0.550
SME24	0.600	0.749	0.600
SME25	0.465	0.680	0.549
SME26	0.584	0.551	0.674
SME27	0.465	0.621	0.365
SME28	0.540	0.562	0.361
SME29	0.736	0.535	0.662
SME30	0.599	0.622	0.422

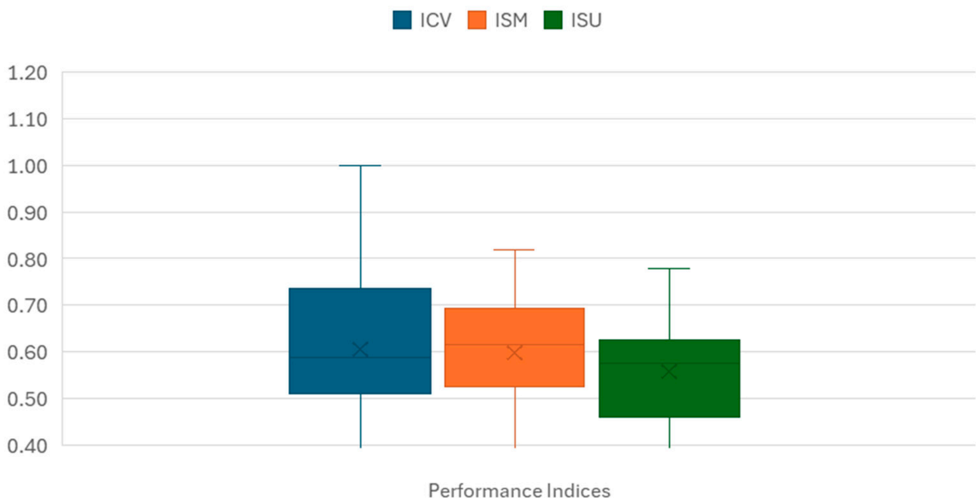

Figure 3. Distribution of performance indices across SMEs for Value Creation (IVC), Strategic Management (ISM), and Sustainability (ISU).

5.3. Global Digital Impact Index (GDII)

Based on the dimension-level indices, the Global Digital Impact Index (GDII) was computed for each SME as an aggregated measure of digital transformation performance.

By integrating IVC, ISM, and ISU, the GDII enables a comprehensive and balanced assessment of digital transformation performance, allowing SMEs to be compared and ranked according to their overall digital impact across multiple organizational dimensions. Table 6 presents the resulting GDII values and the corresponding ranking of the simulated SMEs.

Table 6. Global Digital Impact Index (GDII) and SME ranking (Source: Author's own elaboration).

Rank	SME	GDII	Rank	SME	GDII
1	SME11	0.762	16	SME6	0.582
2	SME10	0.720	17	SME15	0.581
3	SME13	0.714	18	SME19	0.569
4	SME20	0.676	19	SME25	0.565
5	SME18	0.672	20	SME5	0.564
6	SME23	0.652	21	SME4	0.556
7	SME21	0.651	22	SME30	0.548
8	SME3	0.650	23	SME1	0.527
8	SME24	0.650	24	SME22	0.518
10	SME29	0.644	25	SME7	0.504
11	SME16	0.628	26	SME28	0.488
12	SME17	0.622	27	SME27	0.484
13	SME26	0.603	28	SME9	0.482
14	SME12	0.594	29	SME14	0.476
15	SME8	0.587	30	SME2	0.331

As shown in the GDII results, the simulation produces a differentiated ranking structure among the simulated SMEs. Enterprises that are at the top of the ranking (SME11, SME10, SME13) receive consistently high scores across the three dimensions, which within the simulation environment may indicate a more balanced digital transformation profile. SMEs that occupy lower ranking positions (SME2, SME14) receive comparatively lower scores, particularly in the Sustainability dimension.

This result illustrates how the proposed framework captures differences across the three evaluation dimensions within the simulated dataset. Computational exercise suggests that balanced performance across operational, strategic, and sustainability dimensions contributes to higher GDII values, whereas stronger performance in only one dimension may not necessarily lead to a higher overall ranking.

It should be noted that the GDII is a relative performance indicator derived from the Fuzzy TOPSIS procedure. Consequently, differences in GDII values should be interpreted as differences in proximity to the ideal multidimensional profile rather than as absolute measures of digital transformation performance. For example, the difference between GDII values of 0.762 and 0.720 indicates a relatively small improvement in overall proximity to the ideal solution, whereas larger differences across the ranking reflect more pronounced variations in the multidimensional performance profiles generated within the simulation environment.

While based on simulated data, the computational exercise suggests that the proposed framework can differentiate performance profiles and support comparative analysis under conditions of uncertainty. Figure 4 illustrates the distribution of GDII values across the simulated SMEs.

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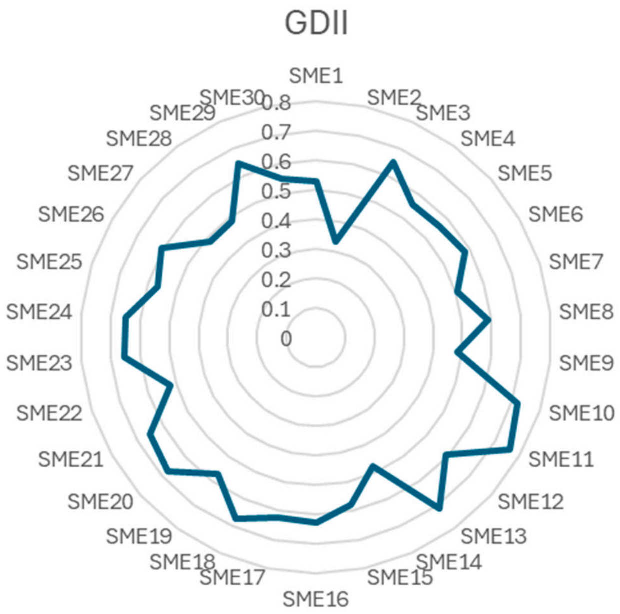

Figure 4. Distribution of Global Digital Impact Index (GDII) values across simulated SMEs. (Author's own creation).

5.4. Sensitivity Analysis of Dimension Weights

Given that the Global Digital Impact Index (GDII) is obtained through the aggregation of the Value Creation Index (IVC), Strategic Management Maturity Index (ISM), and Sustainability Index (ISU), the weighting structure adopted may influence the resulting rankings. Although equal weights were selected in the baseline model to ensure methodological neutrality during the computational validation phase, alternative weighting schemes may reflect different managerial priorities, sectoral contexts, or strategic objectives.

To assess the robustness of the proposed framework, a sensitivity analysis was conducted using three alternative weighting scenarios in addition to the baseline equal-weight configuration. The alternative scenarios were designed to represent situations in which one of the three dimensions receives greater strategic importance. The weighting structures considered are presented in Table 7.

Table 7. Dimension-level weighting schemes adopted in the sensitivity analysis (Source: Author's own elaboration).

Scenario	IVC	ISM	ISU
Baseline (equal weights)	0.333	0.333	0.333
Value Creation priority	0.500	0.250	0.250
Strategic Management Priority	0.250	0.500	0.250
Sustainability Priority	0.250	0.250	0.500

For each weighting scenario, the GDII values were recalculated, and the resulting rankings were compared with the baseline equal-weight configuration using Spearman rank correlation coefficients. This approach enables the assessment of ranking stability under alternative weighting assumptions without altering the underlying dimension-level performance indices. The results are presented in Table 8.

The results show high stability in rankings for all cases of weight variations. The correlation coefficients according to Spearman's rank correlation range between 0.941 and 0.960. This suggests that changes in the weight assigned to the three dimensions will not change the general structure of the resulting rankings significantly.

Table 8. Ranking stability under alternative weighting scenarios. (Source: Author's own elaboration).

Scenario	Spearman Correlation with Baseline Ranking
Value Creation priority	0.960
Strategic Management Priority	0.941
Sustainability Priority	0.950

From a methodological perspective, these findings provide additional evidence regarding the robustness of the proposed framework. Although alternative weighting approaches such as expert-based weighting, Analytic Hierarchy Process (AHP), Fuzzy AHP, entropy weighting, or Best–Worst Method could be employed in future empirical applications, the present computational exercise indicates that the GDII rankings remain relatively stable under different strategic weighting priorities.

The consistently high Spearman rank correlations observed across the alternative weighting scenarios indicate that the framework produces stable rankings despite changes in dimension-level priorities. This finding suggests that the GDII is not excessively sensitive to moderate variations in weighting assumptions, thereby supporting the robustness of the proposed framework. From a decision-support perspective, such stability may increase confidence in the use of the model for comparing Digital Transformation performance under different strategic priorities.

Consequently, the sensitivity analysis suggests that the use of equal weights constitutes a reasonable baseline assumption during the model-validation stage, while highlighting the analytical stability of the proposed decision-support framework under moderate variations in dimension-level weighting schemes.

6. Discussion

The simulation results illustrate the analytical potential of the proposed framework to assess the multidimensional effects of digital transformation in small and medium-sized enterprises (SMEs). The proposed integration of fuzzy multi-criteria decision-making and the structured set of performance dimensions enables the model to capture the complex relationships between the various effects of digital transformation in a comprehensive manner.

The simulation results are consistent with the structural logic embedded in the analytical propositions developed in Section 3.5. The dimension-level indices demonstrate that the proposed framework can generate differentiated performance profiles across the three evaluation dimensions when applied to simulated digital transformation assessments. Furthermore, the GDII illustrates the analytical value of an aggregated multidimensional approach to assessing digital transformation performance.

The dimension-level indices indicate heterogeneous performance patterns, illustrating how digital transformation effects may be distributed differently across organizational domains within the simulation environment. Specifically, higher scores in the value creation dimension are consistent with criteria related to efficiency, innovation, and customer interaction, which is in line with previous evidence of the direct and immediate benefits of digital technologies for enterprises (Parida et al., 2019; Verhoef et al., 2021).

In contrast, the performance in the strategic dimension reflects the role of managerial competencies and governance systems in digital transformation. Higher scores in the strategic dimension are consistent with stronger integration of digital technologies in the decision-making process, which is in line with the dynamic capabilities view of digital transformation (Sebastian et al., 2020; Warner & Wäger, 2019). This interpretation is also consistent with the view that successful digital transformation depends not only on technological adoption but also on managerial behavior, governance quality, and organizational capabilities that support strategic alignment and organizational readiness (Saputra et al., 2026).

The greater variability observed in the sustainability dimension suggests that higher digital transformation scores do not automatically translate into higher sustainability scores within the simulation scenario. Instead, sustainability outcomes appear to depend on the alignment of digital transformation and sustainability strategy. This observation is in line with the notion of the active integration of sustainability in digital strategy rather than its emergence as a secondary effect of digital transformation (George et al., 2021; Kraus et al., 2022).

The application of the Global Digital Impact Index illustrates the potential value of the aggregated approach. The application of the Value Creation Index (IVC), the Strategic Management Maturity Index (ISM), and the Sustainability Index (ISU) in the form of a composite indicator enables a holistic approach to measuring digital transformation performance, as previously discussed as a shortcoming of one-dimensional approaches in the literature (Vial, 2019; Verhoef et al., 2021). Moreover, the computational exercise suggests that balanced scores across the three dimensions are associated with higher GDII values within the simulation environment.

From a methodological perspective, the proposed framework demonstrates how qualitative managerial assessments can be translated into comparable dimension-level indicators with linguistic variables and triangular fuzzy numbers. This enables the systematic evaluation of Value Creation, Strategic Management Maturity, and Sustainability under conditions of uncertainty while avoiding the imposition of artificial precision that is often difficult to justify in SME contexts.

It is important to highlight that the investigation is based on simulated data and is not intended to contribute to empirical generalization. Rather, the findings of the investigation serve to validate the internal consistency of the proposed framework and its analytical behavior. As such, the model is clearly capable of generating a differentiated structure of performance and supporting a comparative evaluation within contexts of uncertainty.

Overall, the investigation contributes to the literature through the development of a multidimensional and uncertainty-sensitive evaluation framework that integrates value creation, strategic management maturity, and sustainability within a single analytical framework. This enables a holistic understanding of the impact of digital transformation on SME performance. Furthermore, the sensitivity analysis indicates that the resulting rankings remain relatively stable under alternative dimension-level weighting schemes, providing additional evidence regarding the robustness of the framework.

7. Conclusions

Digital transformation has asserted itself as a key change driver for small and medium-sized enterprises; however, assessing the multifaceted impact of DT remains a challenging endeavor owing to complexity, uncertainty, and the qualitative nature of many performance indicators. Considering these limitations, the current research introduces a decision-support framework for evaluating the impact of DT on SMEs across three critical dimensions: Value Creation, Strategic Management Maturity, and Sustainability.

By incorporating fifteen evaluation criteria within a fuzzy multi-criteria decision-making approach, the proposed framework provides a means of translating qualitative managerial judgments into quantitative performance indicators. The use of Fuzzy TOPSIS methodology addresses uncertainty while maintaining analytical consistency to produce dimension-level indicators and a composite Global Digital Impact Index (GDII).

Simulation results illustrate the analytical consistency of the proposed framework and its ability to generate differentiated performance profiles across the simulated SMEs. The proposed framework also illustrates how digital transformation effects may vary across organizational dimensions within the simulation environment, reinforcing the value of a multidimensional approach rather than focusing on isolated indicators of DT impact.

From a theoretical point of view, the present research contributes by proposing an integrated evaluation framework to jointly address value creation, strategic capability, and sustainability aspects. From a methodological point of view, the present illustrates the applicability of fuzzy MCDM methods for modelling complex organizational phenomena characterized by ambiguity and subjective evaluation. From a practical point of view, the framework may provide a structured basis for future decision-support applications aimed at supporting SME managers and policymakers in the evaluation of digital transformation initiatives from a multidimensional perspective. The framework may be applied during digital transformation planning, monitoring, or review stages. The evaluation can be performed using qualitative managerial assessments collected through structured questionnaires covering the fifteen evaluation criteria. These values of IVC, ISM, and ISU provide decision makers with insights into areas of strength and weakness within each of the three domains, while GDII provides a general evaluation of the digital transformation performance. Such information may support decisions regarding digital investment priorities, capability development initiatives, and sustainability-oriented actions.

As for the limitations of the present research, several aspects should be acknowledged before drawing broader conclusions regarding the applicability of the framework. First, the use of simulated data limits the generalizability of the results and does not allow empirical validation of the proposed framework. Consequently, the findings should be interpreted as evidence of the internal consistency and computational behavior of the model rather than as evidence of actual SME performance. Second, although the sensitivity analysis indicated a high degree of ranking stability under the weighting scenarios considered in this study, alternative weighting schemes and expert-derived weights may produce different outcomes in specific organizational, sectoral, or national contexts and should therefore be further investigated. Third, the criteria included in the framework were selected through a literature-driven process and were not validated through expert panels or practitioner-based assessment procedures. In addition, the linguistic assessment scale and associated fuzzy representations may introduce a degree of subjectivity, while the framework was not calibrated for specific industries and therefore may not fully capture sector-specific characteristics of digital transformation. Finally, the integration of hybrid decision-making approaches was not explored, and the framework was evaluated exclusively using Fuzzy TOPSIS.

Future research should therefore focus on empirical validation using real SME data, sector-specific and cross-country applications, expert-based validation and weighting procedures, and comparisons with alternative MCDM approaches such as AHP, Fuzzy AHP, Best–Worst Method, and entropy-based weighting techniques. Such studies would provide additional evidence regarding the applicability, robustness, and generalizability of the proposed framework.

Overall, the present research demonstrates the computational feasibility, internal consistency, and analytical applicability of a multidimensional framework for assessing Digital Transformation under conditions of uncertainty. The proposed framework provides a foundation for future empirical validation and application using real SME data.

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Appendix A

This appendix presents the linguistic decision matrix generated during the controlled stochastic simulation process. The evaluations were assigned using probabilistic rules centered on moderate to high levels of digital maturity and subsequently converted into triangular fuzzy numbers (TFNs) for the application of Fuzzy TOPSIS methodology.

Table A1 presents the complete linguistic evaluation matrix used as input for the fuzzy multi-criteria decision-making procedure.

Table A1. Linguistic evaluation matrix.

SME	VC1	VC2	VC3	VC4	VC5	SM1	SM2	SM3	SM4	SM5	SU1	SU2	SU3	SU4	SU5
SME1	H	H	L	H	M	H	M	H	H	M	M	M	H	M	H
SME2	H	M	H	L	L	M	L	M	M	L	M	H	L	L	VH
SME3	H	M	M	H	H	VH	M	VH	VH	H	M	M	H	VH	M
SME4	M	H	VH	H	L	VH	M	H	M	L	H	H	M	VH	M
SME5	M	H	M	M	H	H	M	VH	H	H	L	VH	L	H	H
SME6	H	H	M	VH	L	M	H	H	VH	M	H	L	H	M	VH
SME7	M	VH	H	VH	H	L	H	M	VH	VL	H	M	H	L	L
SME8	H	M	H	H	M	H	M	H	H	L	M	H	H	VH	H
SME9	H	H	M	H	VH	L	M	M	M	H	M	M	M	M	M
SME10	VH	H	VH	H	H	VH	H	M	VH	H	L	H	M	H	VH
SME11	H	VH	H	H	H	H	VH	H	H	H	H	M	VH	H	VH
SME12	H	H	M	H	VH	H	H	H	M	L	H	M	H	H	M
SME13	H	H	VH	M	VH	H	H	H	VH	M	H	VH	M	VH	M
SME14	M	M	H	M	M	M	M	VH	M	H	H	M	H	L	M
SME15	H	VH	H	H	H	H	M	H	H	H	H	L	H	L	L
SME16	H	M	VH	M	M	H	H	VH	VH	H	L	M	M	H	VH
SME17	M	M	VH	M	VH	M	VH	H	VH	M	H	H	M	VH	L
SME18	H	VH	L	VH	VH	M	H	H	VH	H	M	M	M	H	VH
SME19	H	M	VH	H	M	M	M	H	H	M	H	H	M	M	H
SME20	VH	VH	VH	VH	VH	L	H	M	VH	VH	VH	VL	M	M	M
SME21	M	VH	M	VH	M	VH	H	H	H	M	H	H	M	H	H
SME22	L	VH	M	H	M	M	H	H	H	M	M	L	M	H	VH
SME23	VH	VH	M	H	VH	VH	L	VH	H	M	M	H	H	M	M
SME24	M	H	VH	M	H	H	VH	M	VH	H	VH	M	H	M	M
SME25	H	M	H	M	M	M	VH	VH	H	M	H	H	M	M	M
SME26	L	H	VH	M	VH	H	M	M	VH	M	H	H	M	H	H
SME27	H	M	H	M	M	H	M	M	VH	H	VL	L	VH	M	M
SME28	H	M	H	M	H	H	H	H	L	H	H	L	L	M	M
SME29	H	M	VH	H	VH	VH	VH	M	L	M	VH	H	M	H	M
SME30	H	H	VH	H	L	H	H	H	VH	L	H	M	M	M	L

Simulation Parameters and Reproducibility: The linguistic evaluations presented in Table A1 were generated using predefined probability distributions for the five linguistic categories (VL, L, M, H, and VH), with different distributions assigned to each dimension of the framework. For Value Creation, the probabilities were [0.01, 0.06, 0.30, 0.43, 0.20]; for

Strategic Management Maturity, [0.02, 0.08, 0.32, 0.40, 0.18]; and for Sustainability, [0.04, 0.14, 0.38, 0.32, 0.12]. These distributions were selected to create a validation environment characterized by moderate to relatively high levels of digital transformation while preserving variability across SMEs. To ensure that the simulation can be replicated, a fixed random seed (12345) was used during dataset generation, allowing the same synthetic dataset and Fuzzy TOPSIS results to be reproduced under identical conditions.

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