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Towards a Digital Maturity Model for Rural SMEs: Adapting to Organizational and Contextual Realities in Costa Rica's North Zone

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***Abstract*—Rural SMEs face distinct barriers in digital transformation: infrastructure gaps, cultural constraints, and limited technology access. This paper presents a Digital Maturity Model tailored to these realities, grounded in the TOE framework. The model introduces a hierarchical weighting system with Celerity weights (strategic priorities) and Control parameters (environmental constraints), assessed across five maturity levels with actionable descriptors. An Empathy Map workshop approach ensures human-centered evaluation. The model was refined through a pilot with 11 SMEs in Costa Rica's North Zone, demonstrating its practical applicability and providing formative insights for instrument improvement. The contribution is both practical—offering a diagnostic tool for rural digitalization—and theoretical—advancing context-aware maturity assessment for underserved business environments.**

***keywords*— Rural SMEs, digital maturity, technology adoption, TOE framework, digital transformation**

I. Introduction

Digital transformation represents both a critical opportunity and a significant challenge for Small and Medium-sized Enterprises (SMEs), particularly in rural contexts. While Information and Communication Technologies (ICTs) drive development and enable new business models, rural areas face specific barriers related to infrastructure, organizational culture, and technology access [1], [2]. These constraints affect both adoption rates and the ultimate impact of digital initiatives.

For SMEs, successful technology adoption depends on aligning technological capabilities with organizational readiness and environmental conditions. Evidence suggests that perceived benefits, system complexity, and leadership support are determining factors in adoption decisions [1]. However, implementations misaligned with organizational capabilities can undermine rather than enhance competitiveness. The digital transformation journey should therefore begin with a comprehensive assessment of current capabilities [3].

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Maturity models provide structured frameworks for such assessments, guiding SMEs in defining, prioritizing, and sequencing technology adoption initiatives. Yet existing models rarely capture the realities of rural business and their distinctive barriers. To address this gap, this paper proposes a Digital Maturity Model specifically designed for rural SMEs, grounded in the Technology-Organization-Environment (TOE) framework [4]. The model integrates a hierarchical weighting system that reflects both the degree of control SMEs have over different elements and their relative strategic priority.

This approach ensures contextual relevance while providing actionable guidance. Assessment items are structured across five maturity levels, each defined through description, observable elements, tools/processes, and advancement guidelines. Additionally, the model incorporates an Empathy Map-based workshop approach to ensure human-centered evaluation. The result is a practical yet theoretically grounded tool that supports rural SMEs in their digital transition.

II. Theoretical Framework and Related Work

The digitalization of SMEs, particularly in rural settings, requires approaches that account for structural constraints amplifying common adoption barriers [5]. Our model builds upon the Technology-Organization-Environment (TOE) framework [4], which effectively captures the three critical dimensions influencing innovation in resource-constrained contexts. This section reviews literature across these dimensions, highlighting gaps in existing tools for rural digitalization.

A. Digital Maturity Models and Organizational Capabilities

For rural SMEs, digital maturity cannot be meaningfully assessed without considering organizational capabilities for adaptation and learning. This integrated perspective acknowledges that maturity assessments achieve their full relevance only when grounded in these capabilities—an aspect that becomes particularly critical in resource-constrained environments.

International frameworks from consultancies like Deloitte and Capgemini [6]–[8] and established standards including ITIL [9], COBIT [10], NIST CSF [11], and ISO/IEC 33000 [12] provide structured digital transformation pathways. However, their direct application in rural SMEs is limited by assumptions of stable organizational structures, dedicated IT departments, and significant financial resources [2], [13]. As noted by Amaral and Peças [14] and Prause [15], maturity models require adaptation for SMEs, especially in contexts with limited infrastructure and managerial capacity. Colli [16] further critiques these assumptions as contrasting sharply with rural SME realities characterized by organizational fragility and resource scarcity.

Efforts like the *DIGROW* framework by [17], grounded in dynamic capabilities theory, represent progress by focusing on SME growth opportunities. However, such models often overlook the distinctive challenges of *rural* SMEs, including exacerbated infrastructure limitations, territorial isolation, and unique environmental dependencies.

For resource-constrained rural SMEs, dynamic capabilities—adaptation, learning, and strategic resource reconfiguration—are not merely advantageous but prerequisites for meaningful digitalization [18]. Empirical studies consistently identify knowledge gaps and strategic misalignment as core barriers. Research by [14], [19] shows that successful digitalization often emerges through learning-by-doing approaches and strategic reconfiguration of existing resources. This is complemented by [20], whose large-scale study found the primary impediment to be a fundamental *perception gap* at the managerial level regarding digital technologies' strategic importance.

Leadership, organizational culture, and these dynamic capabilities are critical determinants of digital maturity. Studies on "Made in Italy" SMEs demonstrate that sensing digital opportunities and learning from market trends—often driven by entrepreneurial leadership—can be more decisive than adopting advanced technologies [21]. International standards like ISO 30401 on Knowledge Management [22] and ISO 56003 on innovation partnerships [23] offer valuable guidance, though their formal requirements may overwhelm rural SMEs. Our model addresses this by translating dynamic capability principles into the practical structure of the TOE framework, directly tackling the *perception gap* while operationalizing complex standards into context-aware indicators.

B. Technology Adoption in Rural SMEs

Empirical studies consistently identify pervasive barriers to technology adoption in rural SMEs, including chronic connectivity limitations, scarcity of trained personnel, high implementation costs, and cultural resistance to change [2], [14], [19]. These barriers have been further documented in analyses of models and perspectives for digital adoption in rural contexts, highlighting the multidimensional nature of digital transformation challenges [24]. This aligns with the *Technology* dimension of the TOE framework, which evaluates firms' access to and capacity to integrate digital tools [1]. Studies in emerging markets reveal that when technological readiness is low, SMEs tend to focus on familiar tools and require external facilitation for advanced initiatives [25].

Recent applications of artificial intelligence in diverse Costa Rican business sectors, including real estate and education, demonstrate that advanced digital technologies can significantly accelerate processes, reduce costs, and enhance decision-making [26]. These findings validate the potential value of digital transformation for SMEs while highlighting that rural contexts require additional considerations for infrastructure and skills limitations.

Research by Amaral and Peças emphasizes that digitalization must holistically integrate technology, business processes, and organizational culture [19]. Their work demonstrates that successful initiatives often involve low-cost, high-impact changes leveraging familiar tools rather than advanced hardware, thus addressing SME resource and skills constraints.

These challenges reflect broader deficiencies in peripheral entrepreneurial ecosystems. [27] synthesizes barriers into six interconnected domains: limited finance access, talent drain to urban centers, less supportive socio-cultural environments, deficient infrastructure, small local markets, and ill-adapted policies. This systemic perspective underscores that technological adoption is deeply constrained by the surrounding ecosystem.

In response, frameworks like Rural Living Labs (RLLs) have emerged as collaborative platforms fostering digital innovation in constrained environments. [28] contextualizes RLLs as open innovation ecosystems where SMEs can test and adapt technologies with reduced risk, directly addressing finance and talent barriers while fostering supportive socio-cultural environments.

Digitalization can significantly enhance customer value creation through improved brand awareness, engagement, and market reach [21]. For rural firms facing market isolation, these capabilities are particularly vital. However, entrepreneurs often face a profound awareness–action gap, recognizing benefits but lacking implementation knowledge, strategic roadmaps, or financial means [29]. Comparative studies reveal significant SME deficiencies: [30] found 63% lacked formal digital strategies, while [31] identified misalignment between managers' understanding of digital transformation and the actual impact of implemented tools.

Conversely, strategic digital adoption enhances resilience and sustainability for rural businesses operating with limited access to global networks. Simple digital tools providing production visibility and improved planning exemplify this potential [19]. Research by [32], [33], and [34] collectively emphasizes that digital adoption must be progressive, participatory, and closely linked to organizational transformation—a perspective aligning with our model's rationale for bridging the awareness–action gap through context-sensitive digitalization pathways.

Taken together, these findings reinforce the suitability of the Technology–Organization–Environment (TOE) framework

for analyzing rural SME digitalization, as it systematically captures the interplay between technological access, organizational adaptability, and environmental constraints—precisely the dimensions our maturity model operationalizes.

C. Territorial Adaptations and Public Policies

Digital transformation in rural areas requires alignment with public policies and territorial strategies, where local actors (universities, municipalities, associations) play a crucial supporting role [5]. However, the persistent urban-rural digital divide—marked by gaps in connectivity, technology access, and digital skills—hinders the integration of rural businesses into the digital economy [35]. This challenge manifests in contexts such as the Welsh agri-food sector and Colombia's coffee sector, where limited broadband access constrains business proactivity and growth [5], [36].

This dimension aligns with the *Environment* component of the TOE framework, which evaluates how external actors, regulatory frameworks, and support infrastructure influence innovation [1], [2], [37]. The digital maturity of rural SMEs is closely linked to their ability to integrate into local innovation ecosystems and access support programs [19], [32]. Public policies are therefore fundamental not only for providing digital infrastructure but also for fostering digital skills and promoting an innovation culture, helping prevent talent drain and enabling sustainable digital adoption within supportive ecosystems [5], [35], [36].

In summary, while multiple frameworks and studies inform our understanding of SME digitalization, few explicitly account for the compound limitations that rural firms face across the three TOE dimensions. By building upon the TOE model and reinforcing it with empirical and normative findings, including insights from the dynamic capabilities perspective in traditional SMEs [21], our approach provides a context-sensitive structure for evaluating digital maturity in rural SMEs. The following section details the construction of our Digital Maturity Model, which integrates these principles into a practical and scalable tool.

III. Research Methodology

The development of the Digital Maturity Model for rural SMEs was based on the principles of Design Science Research (DSR) [38], which provides a framework for creating and evaluating artifacts that address practical problems. The process combines theoretical grounding with iterative refinement to develop a contextually aware and applicable assessment tool. The model was constructed through an iterative process comprising three key stages, detailed in the following subsections.

A. Theoretical Grounding and Initial Design

The process began with a comprehensive literature review focused on the TOE framework, existing digital maturity models, and the documented challenges of rural SMEs. This foundation informed the initial design of the model, leading to the selection of the three core dimensions (Technology, Organization, Environment) and a preliminary set of categories. The resulting initial framework incorporated four principal features: (i) a categorization system aligned with the TOE dimensions, (ii) a strategy to explore these dimensions using the Empathy Map during assessment, (iii) descriptive maturity levels designed to provide contextualized guidance, and (iv) a hierarchical weighting scheme reflecting both priority and degree of organizational control.

B. Refinement through Internal Analysis and Simulation

Following the initial design, a specific working session was conducted with the entire research team to review and refine the proposed model. The session began with a comprehensive presentation of the model's core principles: its objective in the context of rural digitalization, its theoretical foundation in the TOE framework, the structure of the thematic questions, the integration of the Empathy Map as a guiding tool, the five maturity levels, and their detailed characterization components.

The core of the session focused on case analysis and role-playing exercises to empirically test the model's application. Fictional profiles of rural SMEs were created, and team members adopted the roles of entrepreneur and facilitator. This simulation served to evaluate the relevance, clarity, and feasibility of the assessment items, the flow of the workshop, and the usefulness of the maturity level definitions in providing practical feedback.

The feedback from this exercise allowed for the adaptation of the theoretical concepts into practical and context-aware indicators. It specifically revealed the following key points:

- The need to rephrase certain questions for greater clarity and to avoid ambiguities.
- The importance of facilitators providing examples or context to the participants (entrepreneurs, business owners, managers, or representatives) to help them better understand the intent behind the questions and the relevance of their responses.
- A recognized need to have specific maturity indicators not only per dimension and category, but also a consolidated global maturity score. This global indicator was deemed important to provide SMEs with a general perspective on their overall digital maturity and to track their evolution. Furthermore, it was identified as a tool of interest for the research team to analyze and compare these businesses, and validate the model's consistency. This consensus directly led to the decision to incorporate the global scoring system detailed in Subsection IV-E.

The insights and refinements from this internal session were incorporated into the model's design. This updated version was subsequently employed in the preliminary field validation.

C. Preliminary Field Validation

The refined model was applied with 11 rural SMEs from Costa Rica's North Zone to test the workshop format, the integration of the Empathy Map as a facilitation tool, and the clarity of the questions from the entrepreneurs' perspective.

The participating businesses represented five productive sectors: Tourism (6 SMEs), Agroindustry (1), Agrotourism (1), Ecotourism (1), Commerce (1), and Services (1).

Feedback from this pilot informed several refinements, including rephrasing questions where ambiguities were identified and developing facilitator guidelines to provide contextual examples that help entrepreneurs connect questions to their business realities.

The sample includes diverse sectors, but its size and limited representativeness preclude statistical generalization. The systematic quantitative validation of the model—including statistical analysis of GMI distributions, sectoral comparisons, and reliability testing—requires a larger sample and constitutes the next phase of this research, currently underway.

IV. Digital Maturity Model for Rural SMEs

This section presents the Digital Maturity Model resulting from the development process described in Section III. The model is designed to assess the readiness for digital transformation of SMEs in rural contexts and is grounded in the TOE framework. This framework provides a structured lens for examining technology adoption by integrating organizational capabilities, technological resources, and environmental factors, making it particularly suitable for capturing the distinctive conditions of rural SMEs.

The TOE framework was selected for its capacity to address the holistic context of rural businesses, where resource limitations and external constraints often play a decisive role in technology adoption decisions. Rather than focusing exclusively on technological aspects, it enables an assessment that considers the interplay between internal preparedness, available tools, and the surrounding ecosystem.

The resulting model, refined through the iterative process outlined in the previous section, is structured to provide a context-sensitive evaluation. The following subsections detail its foundational framework, structural components, assessment methodology, and practical application.

A. Theoretical Foundation: The TOE Framework

The TOE framework forms the structural backbone of this maturity model, organizing the assessment into three interdependent dimensions:

- **Technology (T):** This dimension assesses the business's technological infrastructure and capabilities. It encompasses the hardware, software, and digital tools available, the quality of connectivity, the level of cybersecurity awareness, and the foundational digital skills of the personnel.
- **Organization (O):** This dimension evaluates the internal organizational context that enables or hinders digitalization. It includes factors such as leadership's strategic vision for digital transformation, the organizational culture's openness to change and innovation, the adaptability of internal processes, and the existence of training programs to build digital competencies.
- **Environment (E):** This dimension examines the external ecosystem in which the rural SME operates. It considers market dynamics, competitive pressure, the level of support from government policies or local institutions, the regional digital infrastructure, and the opportunities for collaboration within networks or clusters.

B. Model Structure: Dimensions and Adapted Categories

Each of the three TOE dimensions is decomposed into specific, context-aware categories. These categories were refined through the iterative process detailed in Section III to better capture the realities and constraints of rural SMEs.

Technology Categories:

- **Digital Infrastructure:** Assesses the availability and condition of hardware, software, connectivity, and cloud/hybrid solutions.
- **Cybersecurity:** Examines the measures implemented to protect data and technological infrastructure.
- **Digital Adoption & Integration:** Measures the level of adoption of digital tools and their degree of integration into internal processes.
- **Scalability:** Analyzes whether technological infrastructure and solutions can grow or adapt according to business needs.

Organization Categories:

- **Internal Communication:** Evaluates the use of digital tools and practices for internal coordination.
- **Innovation Culture:** Measures the organization's openness to change, willingness to adopt technology.
- **Digital Leadership:** Analyzes the role of leaders in promoting digital transformation.
- **Digital Talent & Training:** Examines the digital competencies of staff, their alignment with positions, and the existence of training plans.
- **Budget & Finance:** Evaluates whether financial resources are allocated for technological adoption and if return on investment is tracked.

Environment Categories:

- **Regulation:** Considers the knowledge and compliance with regulations affecting technology use.
- **Government Support:** Assesses whether the company knows about, accesses, and leverages public incentives for technology adoption.
- **Public Infrastructure:** Analyzes the impact of factors such as electricity, connectivity, or transportation on digitalization.
- **External Task Environment:** Analyzes technological pressure or requirements from strategic allies, suppliers, or customers.
- **Digital Trends & Demand:** Evaluates the company's capacity to identify, anticipate, and respond to new digital demands from the environment.
- **Competition:** Examines whether technological actions in the competitive environment influence internal adoption decisions.

Each of the categories that make up the Digital Maturity Model corresponds to the categories of the original TOE approach, but adapted to the rural context through the refinement process.

C. Assessment Instrument: Thematic Questions Grouped by Category

The assessment instrument consists of 35 thematic questions designed to evaluate digital maturity across all categories of the TOE framework. These questions were carefully formulated to be both practical and comprehensible for business owners, avoiding technical jargon while maintaining diagnostic precision.

The questions are organized hierarchically: first by the three main TOE dimensions (Technology, Organization, Environment), then by their respective categories. This structure facilitates both the application of the instrument and a granular analysis of digital maturity across key dimensions. The number of questions per category varies (from 1 to 6) based on its relative importance and complexity within the rural SME context, as detailed in Table I.

TABLE I Distribution of Thematic Questions by TOE Dimension and Category

Dimension	Category	No. of Questions
Technology	Digital Infrastructure	3
	Cybersecurity	1
	Digital Adoption & Integration	2
	Scalability	2
Organization	Internal Communication	1
	Innovation Culture	6
	Digital Leadership	1
	Digital Talent & Training	4
	Budget & Finance	5
Environment	Regulation	2
	Government Support	1
	Public Infrastructure	1
	External Task Environment	1
	Digital Trends & Demand	2
	Competition	3

Of these 35 questions, 33 are used for the quantitative Global Maturity Index (GMI) calculation. The remaining two questions—both related to the Empathy Map's "Think & Feel" section—capture entrepreneurs' perceptions of technological difficulty and contextual limitations. These qualitative insights inform the workshop discussion but are not included in the mathematical aggregation, as they reflect subjective perceptions rather than verifiable capabilities.

The application of the questionnaire is conducted through a workshop guided by the Empathy Map tool (detailed in Subsection IV-F). This approach ensures the contextual and qualitative nuances of the business are captured, enriching the quantitative assessment. Each response is subsequently evaluated against a defined maturity scale, as explained in the following subsection.

To illustrate the nature of these thematic questions, below are representative examples from each dimension:

- **Environment – Competition:** "Do you consider that technological trends in your industry could represent a competitive advantage if adopted?"
- **Organization – Internal Communication:** "Are tools such as intranet, internal emails, or virtual meetings used as part of the business operation?"
- **Technology – Scalability:** "Can the applications (software) be adapted in terms of functionalities and/or customization?"

This structured yet adaptable approach allows for a comprehensive assessment that captures both the current state of digital maturity and provides actionable insights for improvement.

D. Maturity Levels and Characterization

The model employs a five-level maturity continuum to assess the digital state of rural SMEs. This continuum provides a holistic framework for understanding a company's overall digital journey, from initial awareness to strategic integration. The general characterization of each level is as follows:

- **Level 1 – Initial:** The company recognizes the existence of certain practices or technologies but does not apply them formally. Actions are reactive, scattered, or nonexistent. Informality and a lack of knowledge are predominant.
- **Level 2 – Basic / Awareness:** Minimal or occasional actions have been taken, usually without structured planning. There is partial awareness of the benefits or barriers, but no defined strategy exists. Practices are incipient and not systematized.
- **Level 3 – Intermediate / Structured:** The company has begun to organize its digital practices. Functional, though limited, processes and basic use of tools are observed. Technological adoption is functional but not yet widespread or aligned with strategy.
- **Level 4 – Advanced / Managed:** Technological practices are formalized and aligned with business objectives. Specialized tools are used, planning exists, and results are periodically evaluated. The company seeks to optimize its digital processes.
- **Level 5 – Optimized / Strategic:** Digitalization is an integral part of the company's strategy. There is continuous innovation, impact is measured, and the company adapts proactively to changes. The company leads best practices in its environment and maximizes the value of digital for its competitiveness.

This general description provides the overarching context for the diagnostic. Unlike models that assign a single maturity level to an entire organization, this approach provides a granular diagnosis. Each individual question is evaluated on its own 5-level maturity scale, from *Initial (1)* to *Optimized (5)*. This allows for a precise and actionable assessment, identifying strong and weak points per category.

For every question, each maturity level is defined using a consistent, four-component structure that operationalizes the general concepts into actionable criteria. This structure ensures the evaluation is objective, repeatable, and provides clear guidance for improvement. The characterization for each level of every question includes:

- **Description:** A narrative that translates the general level definition into the context of the specific question, explaining the company's reality for this aspect.
- **Key Observable Elements:** Tangible evidence, behaviors, or resources that an assessor can identify to confirm the rating.
- **Typical Tools / Processes:** The technologies or methodologies commonly associated with this level of maturity for the given aspect.
- **How to Advance to the Next Level:** Concrete, actionable recommendations that guide the company on how to improve this particular aspect.

Example: Diagnosing a Single Question: To illustrate the model's application, consider question 21 from the **Technology** dimension and the **Digital Infrastructure** category:
Question: *"Does the current computer equipment (hardware) and applications (software) meet the technological demand for the business operation?"*

The diagnosis for this question is performed by selecting the maturity level whose description best matches the company's current situation. The following examples show how the general levels are translated into specific definitions for this question:

Level 1 (Initial) for Digital Infrastructure

- **Description:** The company lacks sufficient technological equipment or it is obsolete; processes are mostly manual.
- **Key Observable Elements:** Insufficient or faulty equipment; predominance of manual processes.
- **Typical Tools/Processes:** Notebooks, physical calculators, basic phones.
- **How to Advance:** Acquire at least one functional computer; identify processes that can be digitized.

Level 3 (Intermediate / Structured) for Digital Infrastructure

- **Description:** Each person has functional equipment that allows operation with basic tools (office suite, email, browsing) and at least one business process is supported by technology.
- **Key Observable Elements:** Each person has an operational computer; basic digital tools are used correctly.
- **Typical Tools/Processes:** Windows 10/11 (current/supported version); Google Workspace, LibreOffice; stable internet browsing.
- **How to Advance:** Specialize equipment according to role (design, sales, admin.); implement applications for business processes; improve process response times.

Level 5 (Optimized / Strategic) for Digital Infrastructure

- **Description:** An equipment plan is managed periodically and proactively to meet the business's operational demand.
- **Key Observable Elements:** Modern and scalable infrastructure; prepared for telework and new systems; periodic renewal.
- **Typical Tools/Processes:** Virtualization, remote access, active licenses; dashboards, cloud backups.
- **How to Maintain:** Maintain continuous performance monitoring; proactively evaluate new solutions.

This specific example demonstrates how the consistent application of the four-component structure across all five maturity levels provides a clear, actionable, and graduated pathway. This pathway guides a company from basic technological awareness (Level 1) through structured adoption (Level 3) and ultimately to strategic digital infrastructure management (Level 5). The subsequent section explains how these individual question ratings are aggregated into an overall maturity score, incorporating weighting factors to reflect contextual realities.

E. Global Maturity Index Calculation

The Global Maturity Index (GMI) synthesizes the multidimensional assessment into a single quantitative metric, enabling rural SMEs to benchmark their digital transformation progress and prioritize improvement initiatives.

This comprehensive measure results from a hierarchical aggregation process that systematically combines individual capability assessments with strategic priorities and contextual constraints. As depicted in Figure 1, the GMI calculation follows a structured three-level framework: **individual Question ratings** form the foundational layer, which aggregate into **thematic Category scores** that incorporate organizational priorities through Celerity weights, and finally consolidate into **Dimension-level metrics** adjusted by Control factors. This multi-tiered approach maintains mathematical rigor while accommodating the specific challenges faced by rural enterprises, transforming qualitative self-assessments into an actionable diagnostic tool.

Level 1: Questions - Foundational Assessment: The assessment begins with 33 individual questions, each representing a specific aspect of digital maturity. Every question i receives a maturity rating $M_i \in [1, 5]$, where 1 represents *Initial* maturity and 5 represents *Optimized/Strategic* maturity.

To ensure equitable representation, all questions carry equal base weight:

$$w_i = \frac{1}{33} \approx 0.0303 \tag{1}$$

This uniform weighting prevents any single question from disproportionately influencing the overall assessment while maintaining simplicity in the initial aggregation.

Level 2: Categories - Organizational Prioritization: Questions are organized into 15 thematic categories C_j that group related digital capabilities. Each category C_j contains n_j questions, and the aggregation at this level introduces organizational prioritization:

- **Celerity:** $Y_j \in \{1, 2, 3\}$ represents the relative urgency and importance assigned to each category. Higher values (3) indicate areas requiring immediate attention, while

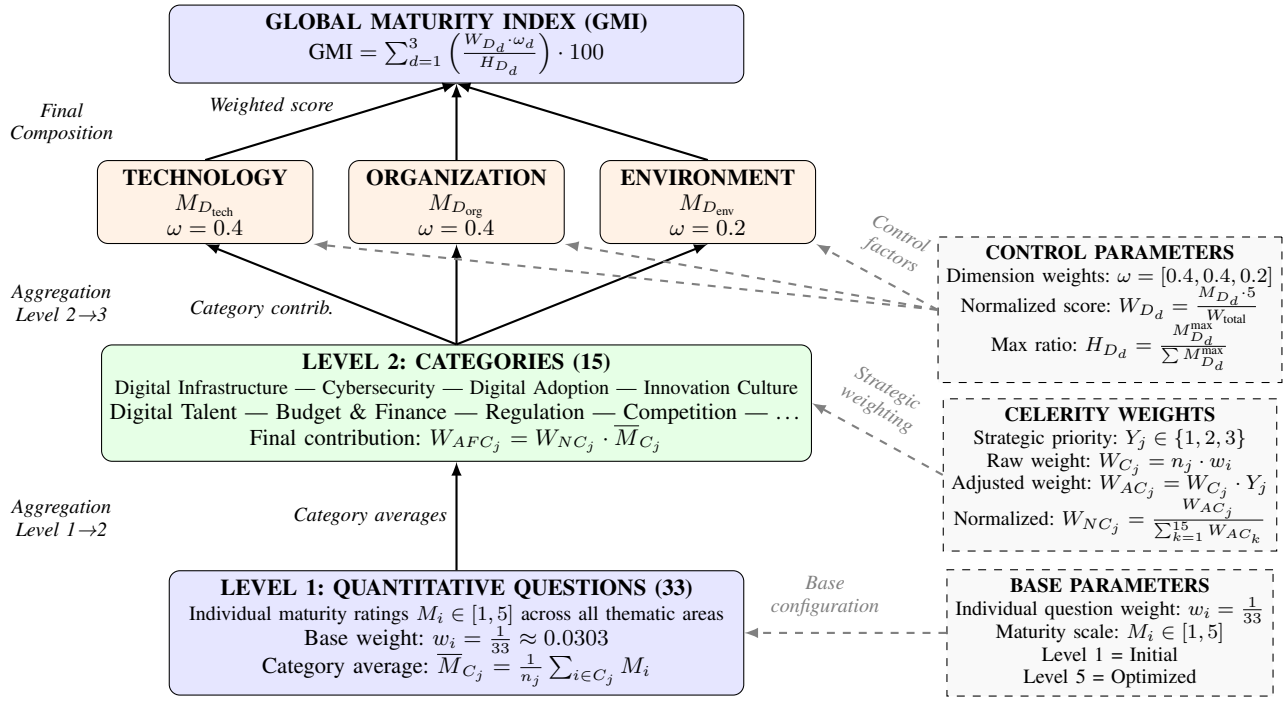

Fig. 1 Comprehensive hierarchical structure and calculation flow of the Global Maturity Index (GMI), illustrating the three-level aggregation process from individual questions through thematic categories to TOE dimensions, with integrated strategic weighting (Celerity) and contextual control parameters.

lower values (1) represent categories that can be addressed with less urgency. The allocation of these weights is based on a structured process that combines expert judgment from the research team (based on the TOE framework, literature on rural SMEs, and input received from SME representatives during the workshop).Future refinements may incorporate consensus techniques such as Delphi to enhance robustness and replicability across facilitators.

- **Raw Category Weight:** The initial weight for each category is proportional to its question count:

$$W_{C_j} = n_j \cdot w_i \tag{2}$$

This ensures categories with more questions naturally have greater influence, reflecting their comprehensive coverage.

- **Celerity-Adjusted Weight:** Organizational priorities are incorporated by scaling the raw weights:

$$W_{AC_j} = W_{C_j} \cdot Y_j \tag{3}$$

This adjustment amplifies the importance of high-celerity categories in the final assessment.

- **Normalized Category Weight:** To maintain mathematical consistency, weights are normalized to sum to unity:

$$W_{NC_j} = \frac{W_{AC_j}}{\sum_{k=1}^{15} W_{AC_k}} \tag{4}$$

This normalization ensures the category weights form a proper probability distribution.

- **Category Contribution:** The final category score combines normalized weights with actual performance:

$$W_{AFC_j} = W_{NC_j} \cdot \overline{M_{C_j}} \tag{5}$$

where $\overline{M_{C_j}} = \frac{1}{n_j} \sum_{i \in C_j} M_i$ is the average maturity of questions within category C_j. This represents the category's contribution to the global maturity index.

Level 3: Dimensions - Contextual Integration: The 15 categories are grouped into three fundamental dimensions D_d based on the TOE framework: Technology (T), Organization (O), and Environment (E). This level incorporates organizational control factors:

- **Dimension Weighted Average:** The maturity for each dimension is calculated as the average of category contributions:

$$M_{D_d} = \frac{\sum_{C_j \in D_d} W_{AFC_j}}{n_{D_d}} \tag{6}$$

where n_{D_d} is the number of categories in dimension D_d.

- **Maximum Dimension Ratio:** Each dimension has a predetermined maximum contribution ratio H_{D_d}, derived directly from the structural configuration of the model—specifically, from the number of quantitative questions per category and the distribution of categories across the three TOE dimensions. These are theoretical parameters calculated as:

$$H_{D_d} = \frac{M_{D_d}^{\max}}{\sum_{d=1}^{3} M_{D_d}^{\max}} \tag{7}$$

where $M_{D_d}^{\max}$ represents the maximum achievable Dimension Weighted Average when every quantitative question in the model achieves the highest maturity level (Level 5). In other words, H_{D_d} reflects the theoretical maximum contribution of each dimension to the GMI under optimal conditions, based solely on the model's design (number of questions per dimension, category weighting, and celerity structure), not on empirical data.

- **Dimension Normalization to 5-point Scale:** Dimension maturities are normalized to a 5-point scale using a total control parameter:

$$W_{D_d} = \frac{M_{D_d} \cdot 5}{W_{\text{total}}} \tag{8}$$

where W_{total} is the *Total Average Weight of Dimensions*, a fixed parameter representing the maximum achievable value across all dimensions when operating at optimal maturity.

- **Dimension Control Weights:** Reflecting the degree of organizational influence over each dimension:

$$\omega_{\text{Environment}} = 0.2$$
$$\omega_{\text{Organization}} = 0.4$$
$$\omega_{\text{Technology}} = 0.4$$

These weights acknowledge that rural SMEs have limited control over environmental factors while having greater agency over organizational and technological dimensions.

Global Maturity Index (GMI) - Final Composition: The comprehensive GMI synthesizes all previous calculations into a single metric:

$$\text{GMI} = \sum_{d=1}^{3} \left(\frac{W_{D_d} \cdot \omega_d}{H_{D_d}} \right) \cdot 100 \tag{9}$$

The division by H_{D_d} creates a performance ratio that compares the actual normalized achievement against each dimension's maximum potential. This approach is designed to:

- **Maintain strategic alignment** through celerity weights that prioritize critical digital capabilities
- **Respect contextual realism** through control factors that acknowledge organizational influence limits
- **Reward performance excellence** when achievements approach theoretical maximums
- **Enable benchmarking consistency** through fixed control parameters

The GMI is intended to provide a multi-perspective measure of digital maturity that reflects both current operational capabilities and strategic positioning. This metric is proposed as a diagnostic tool that aims to enable rural SMEs to:

- Obtain an integrated view of their digital transformation status across critical dimensions
- Identify improvement opportunities based on organizational priority and control levels
- Establish baseline measurements for tracking progression over time
- Inform decisions about resource allocation for digital initiatives
- Compare their digital readiness against theoretical maximum potential

By transforming individual qualitative assessments into a systematic quantitative index, this methodology seeks to provide rural SMEs with actionable guidance for digital advancement while maintaining academic rigor and practical applicability in challenging business environments.

F. The Empathy Map as a Facilitator and Conceptual Framework

To foster an assessment grounded in the lived experience of rural entrepreneurs, the proposed Digital Maturity Model integrates the *Empathy Map* as both a facilitation tool and a conceptual framework. Its application is designed to connect the structured evaluation with the qualitative context of the business.

Within the model, the Empathy Map serves a dual purpose:

1) **A facilitation guide:** During the diagnostic workshop, it helps structure the conversation, allowing facilitators and participants to explore the business's context through segments such as what the business *sees, hears, thinks, feels, says,* and *does*, along with its main *pains* and *gains*.
2) **A conceptual backbone:** Thematic questions in the maturity model are aligned with these empathy dimensions. This relationship is intended to ensure that the quantitative assessment captures not only technical capabilities but also the perceptions, motivations, and external influences affecting digital adoption.

This synergy supports a more natural and human-centered flow during the workshop, as questions are introduced within the context of the empathy dimension being discussed. Participants are encouraged to annotate the map as they reflect, linking their experiential insights to the maturity indicators.

This approach is designed to provide a model diagnostic that is contextually informed, reflecting both operational capabilities and the human factors shaping digital transformation in rural SMEs. The alignment between the map and the questionnaire also offers a framework for subsequent qualitative analysis of workshop outcomes.

V. Discussion

This study set out to develop a digital maturity model for rural SMEs, a segment often overlooked by conventional frameworks. The proposed model, grounded in the TOE framework and refined through an iterative, empathy-driven process, offers several distinctive contributions.

First, unlike generic models [6], [8] or those requiring significant resources [2], [13], it incorporates a hierarchical weighting system with *Celerity weights* (strategic priorities) and *control parameters* (environmental constraints), addressing the awareness-action gap noted in the literature [20], [31]. Second, the integration of the Empathy Map tackles the managerial "perception gap" [20] by creating a structured space

to explore motivations and fears. Third, the GMI calculation compares actual performance against theoretical maximums through control parameters, transforming qualitative insights into a quantitatively grounded diagnostic tool.

The pilot application with 11 SMEs from Costa Rica's North Zone (Section III-C) provided valuable insights into the model's practical applicability and its ability to capture the real conditions of technology adoption in small enterprises. When analyzing the state of digital transformation of the sample, a polarization is observed at the lower levels of the maturity scale: 81.8% (n=9) of the SMEs are classified at the Initial level and 18.2% (n=2) at the Basic level. However, this predominance of low levels should not be interpreted as absolute homogeneity in organizational capabilities.

The internal distribution of the Global Maturity Index (GMI), ranging from 1.00 to 1.99, reveals critical nuances regarding each entity's starting point. This variability could suggests that, while most share a significant digital divide, some SMEs possess minimal structural conditions that position them in a higher state of readiness. In this context, the identification of companies with scores close to the Level 2 threshold indicates a strategic window of opportunity.

Rather than reflecting what researchers assume organizations need, the model enabled the identification of the capacities and motivations expressed by the participating companies themselves.

However, several limitations must be acknowledged. The model requires extensive empirical validation across a broader and more diverse population of rural SMEs. The reliance on self-reported data during workshops, though potentially mitigated by the empathetic approach, remains susceptible to biases. The effectiveness of the assessment is likely dependent on the facilitator's skill, suggesting a need for training guidelines. Finally, the control parameters were derived from the model's specific structural configuration; their generalizability and potential need for calibration in different contexts require further investigation.

Despite these limitations, the model offers a theoretically grounded and practical approach for diagnosing digital maturity and formulating context-sensitive improvement pathways, contributing to the broader goal of inclusive digital transformation.

VI. Conclusions and Future Work

This paper has presented a comprehensive Digital Maturity Model specifically designed to address the unique challenges and opportunities faced by rural SMEs. By building upon the established TOE framework and integrating a hierarchical calculation methodology with Celerity weights and control parameters, the model proposes a context-sensitive approach for evaluating digital maturity. The three-level aggregation process—questions, categories, and dimensions—is intended to provide not only a Global Maturity Index (GMI) but also granular, actionable insights across technological, organizational, and environmental dimensions. The systematic use of control parameters (H_{D_d} and W_{total}) is designed to enable assessment that considers performance relative to theoretical maximums while seeking to maintain mathematical consistency.

The model's development followed a DSR-informed, iterative process that combined literature review, internal expert analysis via case studies and role-playing, and preliminary field validation. This approach sought to establish a theoretical foundation while maintaining relevance to practical application and contextual factors. The incorporation of the Empathy Map is intended to foster a human-centered evaluation process, potentially aligning the assessment with the lived experiences of entrepreneurs and helping to keep the model grounded in their reality.

The immediate future work involves the validation and refinement of the model through larger-scale application. This will include:

- Conducting full-scale pilot workshops with a significant number of rural SMEs across various sectors to collect datasets that allow validation of the GMI calculation methodology.
- Performing relevant statistical analyses (e.g., factor analysis, reliability tests) to assess the construct validity and internal consistency of the assessment instrument and the hierarchical aggregation process.
- Formalizing the methodology for analyzing the qualitative data gathered through the Empathy Map to complement the quantitative GMI scores, potentially enabling richer case studies and deeper insights into the barriers and drivers of digital adoption.
- Investigating the influence of specific industry sectors on digital maturity patterns and GMI scores, as suggested by [2], to explore potential needs for sector-specific adjustments to the control parameters or weighting schemes.
- Exploring the sensitivity of the GMI to variations in the control parameters (H_{D_d} and W_{total}) to establish guidelines for model calibration in different regional contexts. Drawing inspiration from calibration approaches like those used in Function Point Analysis, this would involve developing adaptation mechanisms that allow the model to be tuned according to specific regional or sectoral characteristics, potentially enhancing its contextual relevance and applicability.

Longer-term research directions could include exploring the potential for implementing the assessment tool in a user-friendly digital platform and investigating the development of data-informed recommendation systems based on maturity profiles. The hierarchical structure of the GMI calculation appears suitable for computational implementation and could potentially support context-aware adjustment of improvement priorities.

Ultimately, the aim is for this model to contribute to the ecosystem of tools supporting the digital transition of rural enterprises, thereby helping to address the digital divide and foster sustainable economic development in underserved areas. The systematic yet contextually adaptive approach to maturity assessment presented here offers a foundation for

further academic research and practical applications in rural digitalization.

Future work will also examine how regional industry sectors may influence organizational maturity patterns, considering that [2] indicates that information intensity, business types, and industries can affect technology adoption trends.

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