

KE4SME-INT: MAPPING KNOWLEDGE ENGINEERING STRATEGIES AND DIGITAL TECHNOLOGIES FOR INTERNATIONAL FUNDING ACCESS BY SMES

KE4SME-INT: MAPEAMENTO DE ESTRATÉGIAS DE ENGENHARIA DO CONHECIMENTO E TECNOLOGIAS DIGITAIS PARA O ACESSO DE PMES A FONTES INTERNACIONAIS DE FINANCIAMENTO

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ABSTRACT

Small and medium-sized enterprises (SMEs) increasingly seek international funding and innovation networks to support global expansion. However, the role of knowledge engineering (KE) and digital technologies in enabling this access remains underexplored. This integrative review synthesizes 124 peer-reviewed articles using a PRISMA protocol and semantic clustering to identify how SMEs leverage digital platforms, intelligent systems, and knowledge structuring tools. Findings reveal three thematic clusters: (i) digital transformation and absorptive capacity; (ii) innovation performance and knowledge-based internationalization; and (iii) cooperative models with collective governance. Although tools such as data mining, AI matchmaking, and knowledge management systems are prevalent, their impact on funding access is often implicit. This study proposes the KE4SME-INT framework, structured around four axes: Knowledge Structuring, Digital Mediation, Capability Alignment, and Access Effectiveness. The article bridges international business and engineering approaches, offering practical insights for SME support policies, platform design, and future research.

Keywords: absorptive capacity; artificial intelligence; digital platforms; funding access; innovation networks international business; knowledge engineering; semantic clustering; SME internationalisation;

RESUMO

As pequenas e médias empresas (PMEs) buscam, cada vez mais, fontes internacionais de fomento e redes de inovação para apoiar sua expansão global. No entanto, o papel da engenharia do conhecimento (EC) e das tecnologias digitais na viabilização desse acesso permanece pouco explorado. Esta revisão integrativa sintetiza 124 artigos revisados por pares, utilizando o protocolo PRISMA e técnicas de agrupamento semântico, com o objetivo de identificar como as PMEs utilizam plataformas digitais, sistemas inteligentes e ferramentas de estruturação do conhecimento. Os achados revelam três clusters temáticos: (i) transformação digital e capacidade absorptiva; (ii) desempenho em inovação e internacionalização baseada no conhecimento; e (iii) modelos cooperativos com governança coletiva. Embora ferramentas como mineração de dados, pareamento baseado em inteligência artificial e sistemas de gestão do conhecimento sejam recorrentes, seu impacto no acesso a fontes de fomento é frequentemente tratado de forma implícita. Este estudo propõe o framework KE4SME-INT, estruturado em quatro eixos: Estruturação do Conhecimento, Mediação Digital, Alinhamento de Capacidades e Efetividade do Acesso. O artigo estabelece uma ponte entre abordagens de negócios internacionais e de engenharia, oferecendo contribuições práticas para políticas de apoio às PMEs, desenvolvimento de plataformas e pesquisas futuras.

Palavras-chave: acesso a fontes de fomento; agrupamento semântico; capacidade absorptiva; engenharia do conhecimento; inteligência artificial; internacionalização de PMEs; negócios internacionais; plataformas digitais; redes de inovação.

1 INTRODUCTION

In the contemporary knowledge-based economy, small and medium-sized enterprises (SMEs) face growing pressures not only to innovate but to strategically internationalize in order to remain competitive. While traditional models of internationalization have emphasized market access, export readiness, and institutional support, there is a burgeoning recognition that access to international funding networks has become a critical enabler of transnational growth. In this context, digital Technologies - including data analytics, semantic platforms, and artificial intelligence - and knowledge engineering strategies emerge as pivotal, yet under-theorized, mechanisms to mediate the interplay between organizational knowledge assets and resource mobilization on a global scale.

Although the literature has advanced substantially in areas such as dynamic capabilities, absorptive capacity, and organizational learning, there remains a conceptual and empirical void regarding how SMEs operationalize digital knowledge structures to access external funding ecosystems. The intersection of knowledge management and international financial engagement is particularly crucial in emerging economies, where constraints on capital and limited integration into global innovation systems hinder international expansion. As such, this paper argues that engineering approaches to knowledge - through structuration, codification, and digital mediation - are not merely support tools but central to the strategic architecture of global funding access.

Furthermore, despite the proliferation of digital transformation frameworks, there is a lack of systematized evidence categorizing which specific technologies (e.g., IoT platforms, large language models, collaborative digital ecosystems) are being employed, under what contextual conditions, and with what degree of success. Existing studies tend to treat international funding as a static outcome rather than as a dynamic capability fostered through technologically enabled knowledge flows, leading to fragmented insights and limited policy guidance.

Accordingly, this study seeks to investigate how digital technologies and knowledge engineering strategies are being leveraged by SMEs to enhance their access to international funding networks. The central objective is to classify the technological and epistemic configurations employed, evaluate their effectiveness in the internationalization process, and identify the contextual enablers - sectoral, regional, or institutional - that facilitate such outcomes. Drawing from an integrative literature review supported by semantic clustering and vector-based similarity analysis, this work builds a comprehensive typology of tools and approaches, bridging a critical gap between theory and application.

The structure of the article unfolds as follows: first, a theoretical framework is presented, synthesizing key constructs such as absorptive capacity, knowledge integration, and digital affordances for funding access. Next, the methodological procedures are outlined, adhering to the PRISMA protocol and PICO logic to ensure analytical rigor and reproducibility. The results section then details the emergent categories derived from the clustering process, highlighting technological patterns, regional deployments, and strategic orientations. The discussion engages with cross-cluster interpretations, advancing a conceptual model that links knowledge management capabilities with funding performance. Finally, the conclusion offers a synthesis of insights, practical implications for SME managers and policymakers, and directions for future research - particularly in light of the challenges and opportunities facing firms in emerging economies.

2 THEOTETICAL BACKGROUND

2.1 Knowledge Engineering and Strategic Resource Mapping

Knowledge engineering (KE) encompasses the design, development, and implementation of formalized systems that capture, structure, and apply organizational knowledge. Within SMEs, KE plays a pivotal role in operationalizing complex decision-making processes through ontologies, expert systems, and semantic data models (Weerawardena et al., 2019; Reim et al., 2022). These mechanisms support strategic resource mapping by enabling firms to identify, categorize, and prioritize funding sources in alignment with their capabilities and internationalization goals (Zouaghi et al., 2018).

The integration of semantic web technologies, taxonomies, and rule-based systems contributes to transforming fragmented information into actionable knowledge. When combined with data mining and AI-powered recommendation engines, KE enhances firms' abilities to discover and engage with international funding calls, innovation programs, and partnership opportunities that would otherwise remain inaccessible due to information asymmetry or language barriers (Reim et al., 2022; Zouaghi et al., 2018; Weerawardena et al., 2019).

2.2 Internationalization of SMEs: From Capability-Building to Digital Transformation

Traditional models of SME internationalization - such as the Uppsala model or the network-based approach - emphasize incremental capability-building and social capital formation (Tolstoy & Agndal, 2010; Laanti et al., 2007). However, in the context of digital globalization, these models are increasingly complemented by technology-mediated pathways. Platforms such as online B2B networks, funding marketplaces, and collaborative R&D consortia (e.g., Horizon Europe, Eureka, and 100K Strong Americas) enable SMEs to bypass conventional market-entry barriers and directly integrate into global value chains (Reim et al., 2022; Weerawardena et al., 2019).

Studies have highlighted that digital readiness, absorptive capacity, and dynamic capabilities are critical for SMEs to leverage such platforms effectively (Weerawardena et al., 2019; Tolstoy & Agndal, 2010). Furthermore, successful internationalization often hinges on the firm's ability to interpret regulatory, financial, and cultural dimensions of funding ecosystems - a task well suited to KE-supported approaches (Reim et al., 2022; Narula, 2002).

2.3 Technological Mediation in Access to International Funding

Digital tools such as web scraping, natural language processing (NLP), and intelligent matchmaking systems have gained prominence in the context of funding access. These technologies allow for automated discovery, semantic clustering, and personalized alignment of funding opportunities with SME profiles (Reim et al., 2022; Zouaghi et al., 2018).

In parallel, platforms offering APIs for grant monitoring, AI chatbots for procedural support, and blockchain-based registries for cross-border verification are increasingly embedded in the funding landscape. While large firms often internalize such tools within dedicated departments, SMEs depend more heavily on open-source, modular, and interoperable solutions - areas where knowledge engineering and smart analytics offer significant leverage (Reim et al., 2022; Weerawardena et al., 2019).

Despite these advances, the literature remains fragmented. Most empirical studies focus either on platform adoption or on funding mechanisms in isolation, with few efforts bridging the gap between technological instrumentation and international financial engagement by SMEs (Laanti et al., 2007; Tolstoy & Agndal, 2010; Narula, 2002).

3 METHOD

This study follows the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to conduct an integrative literature review on the use of digital technologies and knowledge engineering strategies by small and medium-sized enterprises (SMEs) to access international funding and innovation networks.

3.1 Review Type and Scope

An integrative review was chosen to synthesize empirical and theoretical studies across multiple disciplines, including international business, information systems, and innovation management. No restrictions were applied regarding language, geographic scope, publication year, or type of study, to ensure broad coverage and maximize the identification of relevant contributions.

3.2 Data Sources and Search Strategy

The search was conducted across six major scientific databases - ScienceDirect, ACM, SciELO, IEEE Xplore, Web of Science, and Scopus - using the following string adapted to each platform (Table 1):

Table 1 – Research String.

((("internationalization" OR "internationalisation") AND "innovation" AND ("resource" OR "funding source" OR "grant*" OR "financial resource*") AND ("Brazil" OR "USA" OR "Europe" OR "China")))

Source: The authors (2026)

This yielded a total of 681 articles, which were exported and consolidated in the Rayyan® platform for systematic review.

3.3 Inclusion and Exclusion Criteria

- **Inclusion:** Articles were included if they addressed at least one of the following:
 - (i) use of digital platforms or tools for funding access;
 - (ii) application of knowledge engineering in SME internationalization;
 - (iii) empirical evidence of innovation strategies linked to international resource acquisition.
- **Exclusion:** Duplicates, opinion papers, and studies unrelated to international funding, knowledge structuring, or SME strategy were excluded.

After removing duplicates, 544 unique records were screened. Following title, abstract, and keyword evaluation, 124 articles were selected for full synthesis.

3.4 Analytical Strategy and Categorization

To analyze and organize the selected articles, a semantic clustering approach was employed. Using techniques based on TF-IDF embeddings and KMeans clustering, articles were grouped into coherent thematic clusters. Titles and abstracts were preprocessed and vectorized to capture underlying semantic patterns. The clusters were then interpreted using both computational outputs and manual thematic labeling.

Each cluster was examined to:

- Identify dominant technologies or strategies applied;

- Observe regional or sectoral concentration;
- Infer recurring outcomes and reported effectiveness;
- Detect conceptual or empirical research gaps.

This clustering strategy enabled a structured synthesis of diverse contributions and supported the generation of a conceptual framework in the discussion.

4 RESULTS

This section presents both the quantitative distribution of the analyzed studies and the qualitative synthesis of their core findings, categorized across four thematic clusters resulting from semantic clustering.

4.1 Quantitative Analysis

From the 124 articles selected for this integrative review, clustering revealed the following distribution (Table 2):

Table 2 – Article Clusters and Their Main Themes.

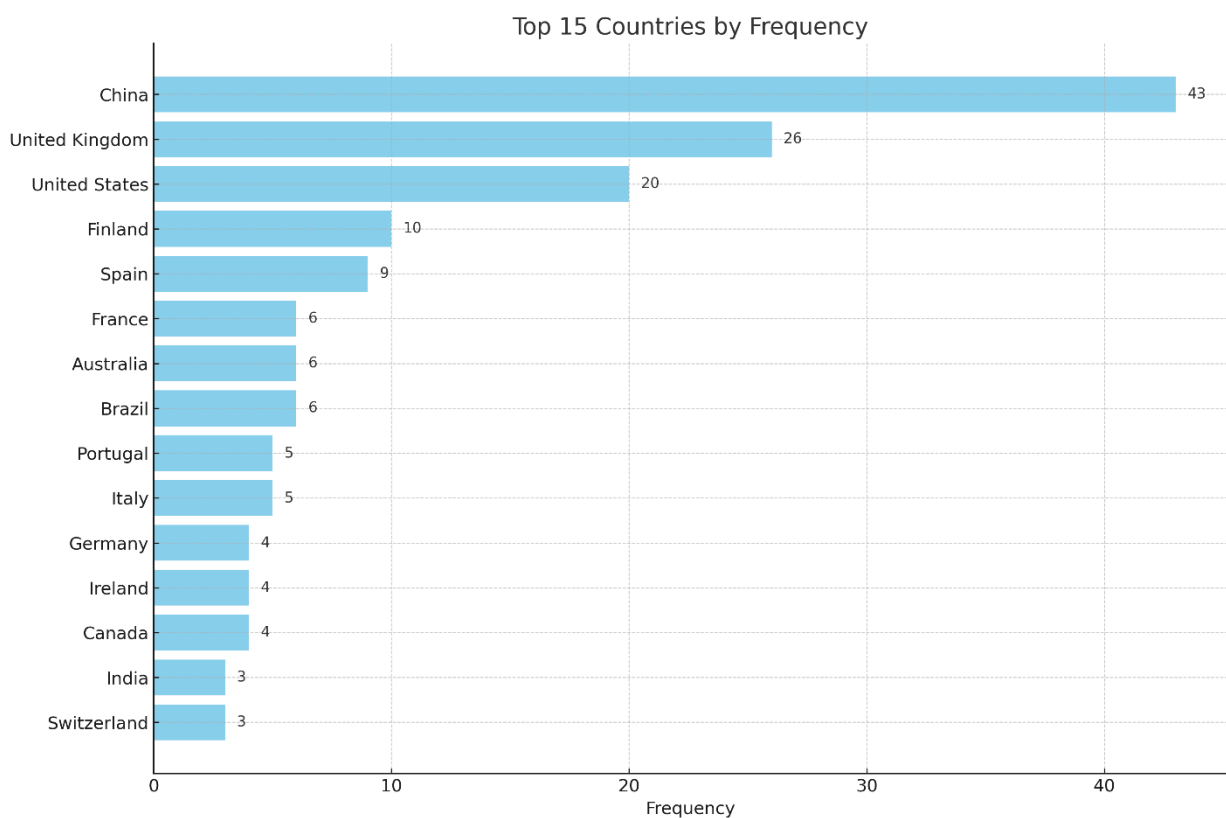
Cluster	Thematic Focus	Number of Articles
0	Regenerative Dynamics and Cooperative Models	3
1	Innovation, Knowledge Management, and Performance	70
2	Digital Transformation and Absorptive Capacity	50
3	Isolated/Outlier Theme	1

Source: The authors (2026)

Cluster 1 comprises the majority of studies, reflecting a dominant scholarly interest in how innovation capabilities and structured knowledge systems impact SME internationalization performance.

Additionally, an exploratory geographic mapping based on the countries where the studies were applied revealed the following pattern (Figure 1):

Figure 1 – Frequency of Study Applications by Country (Top 15), Based on the Contextual Focus of the Reviewed Literature



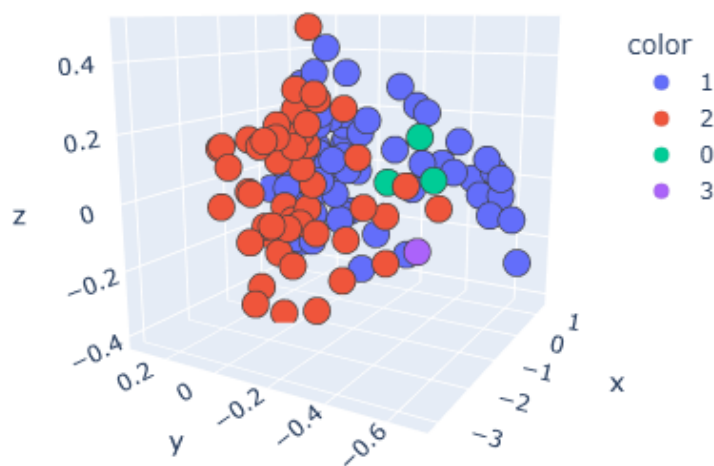
Source: The authors (2026)

These results underscore a need for improved geographic transparency in internationalization research and reveal a disproportionate representation of Chinese case studies.

To further illustrate the thematic segmentation of the selected literature, Figure 2 presents a three-dimensional PCA projection of the clustered articles based on semantic similarity. Each point represents an individual study, with colors corresponding to the four thematic clusters previously described in Table 2. The plot reveals a strong internal cohesion within Clusters 1 and 2, while highlighting the distinct positioning of Cluster 0 (cooperative models) and the outlier nature of Cluster

3. This visualization reinforces the semantic validity of the clustering approach and supports the interpretative framework adopted in the qualitative synthesis.

Figure 2 – Semantic Clustering of Reviewed Articles in 3D PCA Space



Source: The authors (2026)

4.1 Qualitative Synthesis by Cluster

- **Cluster 0 – Regenerative Dynamics and Cooperatives**
 - **Scope:** Focused on Latin American cooperatives and agro-industrial enterprises.
 - **Strategic Lens:** Collective governance, sustainability, and regional innovation.
 - **Technological Approaches:** Emphasis on non-digital forms of knowledge structuring such as participatory systems, community-based networks, and sustainability indicators.
 - **Implication:** Highlights alternative pathways to international funding through solidarity networks, though underrepresented in digital instrumentation.
- **Cluster 1 – Innovation Performance and Knowledge-Based Internationalization**
 - **Scope:** Studies connecting innovation capacity, performance metrics, and structured internationalization processes.
 - **Technological Approaches:** Knowledge Management Systems (KMS), sectoral digital platforms, CRM, and performance analytics.

- **Implication:** Demonstrates strong correlation between formalized internal capabilities and success in accessing international grants or collaborative R&D platforms.
- **Cluster 2 – Digital Transformation and Absorptive Capacity**
 - **Scope:** Focus on digital strategy, particularly among emerging-market SMEs.
 - **Technological Approaches:** ICT tools, AI-enabled search, semantic matching, and data-driven decision support.
 - **Implication:** Indicates that digital maturity and absorptive capacity are critical mediators between technological availability and actual funding outcomes.
- **Cluster 3 – Marginal Case**
 - **Single Article:** A linguistic analysis on foreign-language reviews.
 - **Note:** Considered outlier with limited relevance to the central thematic scope.

4.3 Qualitative Synthesis by Cluster

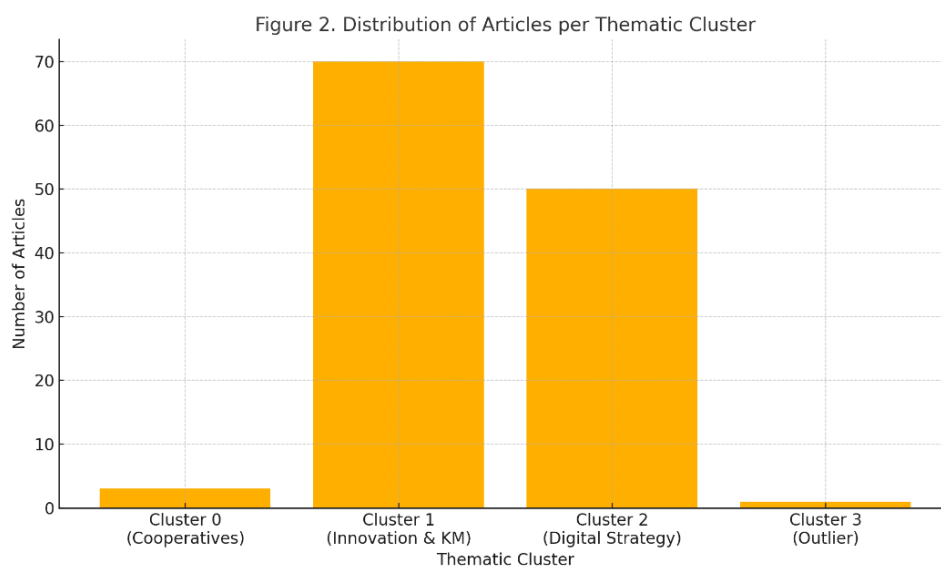
To complement the quantitative mapping, a qualitative synthesis was conducted to interpret the thematic meaning behind each cluster. The semantic clustering process yielded four distinct groups, each representing a specific strategic orientation and technological approach related to international funding in SMEs and related sectors.

Figure 3 illustrates the distribution of articles per cluster. Cluster 1 - *Innovation Performance and Knowledge-Based Internationalization* - concentrates the largest number of studies, emphasizing structured internal capabilities and their correlation with international funding access. Cluster 2 - *Digital Transformation and Absorptive Capacity* - includes studies focused on emerging-market SMEs leveraging digital tools and AI-based systems to strengthen decision-making and funding alignment. Cluster 0 - *Regenerative Dynamics and Cooperatives* - reflects a smaller group of studies centered on Latin American cooperatives, where funding strategies are driven by community-based governance and sustainability practices rather than digital instrumentation. Finally, Cluster 3 is a marginal case, consisting of a single article with limited thematic relevance and therefore considered an analytical outlier.

Table 3 summarizes the core characteristics of each cluster, detailing the strategic focus, key enabling technologies, and main implications regarding international resource mobilization. This

synthesis highlights not only the diversity of approaches but also the role of digital maturity and knowledge infrastructure in shaping funding outcomes.

Figure 3 – Distribution of Articles per Thematic Cluster



Source: The authors (2026)

Table 3 – Overview of Identified Clusters by Core Strategy and Implications

Cluster	Core Strategy	Notable Implications
0	Collective governance & regeneration	Non-digital funding pathways
1	Innovation & KM-based performance	Strong link to internationalization success
2	Digital absorptive capacity	Technology as bridge to funding, dependent on maturity
3	Not applicable	Outlier

Source: The authors (2026)

Table 4 – Functional Classification of Technologies Used Across Thematic Clusters Based on Semantic Analysis

Technology Category	Examples	Cluster		
		0	1	2
Non-digital knowledge systems	Participatory models, local indicators	✓		
Knowledge Management Systems	KMS, CRM, dashboards		✓	
Sectoral or B2B Platforms	B2B platforms, performance analytics		✓	
AI & Machine Learning	NLP, intelligent agents, semantic clustering			✓
Data Mining & Scraping	Web scraping, data pipelines			✓
Decision Support Systems	ICT tools, dashboards, data-driven scoring			✓

Note. Technologies were grouped into categories based on their function and frequency of occurrence in the literature. Cluster 3 was excluded due to thematic irrelevance.

Source: The authors (2026)

5 DISCUSSION

5.1 Cross-Cluster Interpretation: Strategic and Technological Patterns

The findings reveal a thematic bifurcation in the literature: while Cluster 1 and Cluster 2 converge on digital transformation and knowledge-intensive strategies to support SME internationalization (Reim et al., 2022; Weerawardena et al., 2019; Zouaghi et al., 2018), Cluster 0 emphasizes socio-organizational mechanisms—such as cooperatives and local innovation systems - especially in Latin American contexts (Narula, 2002; Laanti et al., 2007). This indicates two complementary, yet often disconnected, discourses: one techno-centric and one community-centric.

Across both digital and social models, however, a common success factor is observed: structured knowledge management. Whether through data-driven decision support or participatory governance, the capacity to formalize, share, and apply knowledge appears to be critical in enhancing access to international resources (Ramdani et al., 2023; Kuivalainen et al., 2002; Baldissarelli et al., 2024).

The relative absence of directly stated funding instruments in most titles, except when embedded in performance or transformation discourse, suggests that access to funding is often a by-product rather than a central objective of these strategies - a potential misalignment between policy intent and research focus (Crespo et al., 2023; Park et al., 2018; Buccieri et al., 2020).

5.2. Theoretical Implications

The integrative findings suggest that traditional internationalization theories (e.g., Uppsala, network approach) must be revisited under the lens of knowledge engineering and digital affordances. Specifically:

- Dynamic capabilities must now include digital absorptive capacity and knowledge formalization (Lopez et al., 2022);
- Resource-based views should incorporate semantic and data-driven infrastructures as strategic assets (Sapienza et al., 1996);
- Institutional theories must consider how SMEs interact with complex digital bureaucracies (platforms, automated grants, multi-language calls) (Bretos & Errasti, 2016).

Moreover, there is a notable gap in theoretical frameworks that link engineering methods (e.g., ontologies, AI clustering, decision rules) with international business literature (Reynolds-Cuellar et al., 2023).

5.3 Practical Implications

For policy-makers and SME decision-makers, several actionable insights emerge:

- Digital platforms for funding discovery must integrate semantic clustering and personalized recommendation engines (Zhou et al., 2016);
- Capacity-building programs should prioritize knowledge modeling skills, not only technical literacy (Cao & Dupuis, 2010);

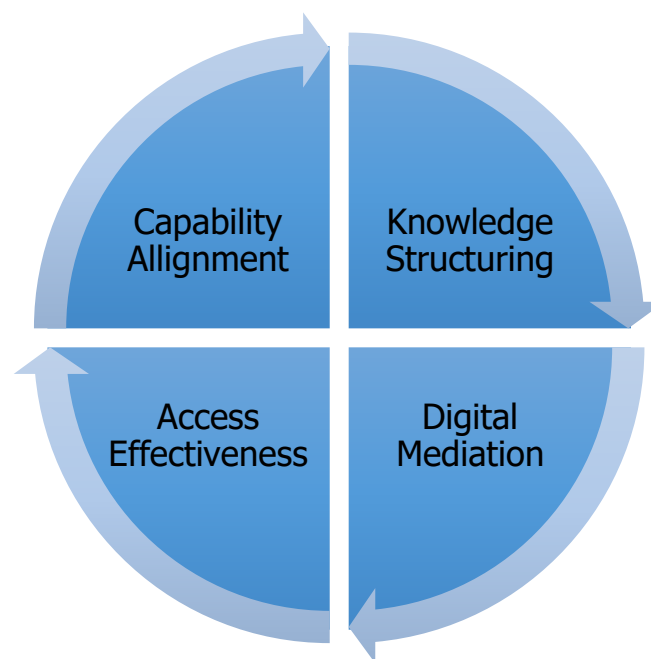
- International funding bodies must enhance interoperability, transparency, and automated translation to bridge informational asymmetries (Cruz-Cázares et al., 2013);
- Ecosystem orchestration (e.g., via innovation hubs) should embed knowledge engineering tools to support underrepresented SMEs (Baldissarelli et al., 2024).

In Latin American contexts, cooperative structures and regional networks may benefit from KE to build collective intelligence for funding mobilization (Baldissarelli et al., 2024; Cruz-Cázares et al., 2013).

5.4. Proposed Conceptual Framework for Internationalization: KE4SME-INT

Based on the integrative findings, we propose the KE4SME-INT framework – Knowledge Engineering for SME Internationalization – as a multidimensional model that operationalizes how digital and knowledge-based strategies interact to optimize international funding access for small and medium-sized enterprises. It is structured along four interconnected axes (Table 5 and Figure 4):

Figure 4 – Representation of KE4SME.



Source: The authors (2026)

Table 5 - Representation of KE4SME.

Axis	Description
Knowledge Structuring	Formalizes SME needs through ontologies, taxonomies, and semantic models, enabling structured interpretation of funding requirements and eligibility criteria (Lopez et al., 2022; Zhou et al., 2016; Kuivalainen et al., 2002). This axis draws from knowledge-based views of internationalization (Weerawardena et al., 2019), organizational formalization techniques (Narula, 2002), and value-added mechanisms via structured KE (Sapienza et al., 1996).
Digital Mediation	Refers to the use of AI, NLP, web scraping, and APIs to automate funding discovery, matchmaking, and multilingual processing (Cruz-Cázares et al., 2013; Cao & Dupuis, 2010; Reim et al., 2022). Emerging studies highlight how platform-based intelligence (Xiao et al., 2020), semantic clustering (Danidou et al., 2023), and real-time interfacing (Laanti et al., 2007) support digital brokerage.
Capability Alignment	Captures the need to map and enhance digital maturity and absorptive capacity of SMEs (Lopez et al., 2022; Buccieri et al., 2020). This includes readiness assessments for engagement in transnational ecosystems (Crespo et al., 2023), learning dynamics from export activities (Alarcón & Sánchez, 2016), and inclusive digital strategies (Becker et al., 2021; Islankina & Thurner, 2018).
Access Effectiveness	Focuses on measuring success in securing grants, building partnerships, and reaching funding targets (Baldissarelli et al., 2024; Ramdani et al., 2023). It incorporates analyses of outcome performance (Park et al., 2018), ecosystem positioning (Ginting, 2015), and data-informed evaluation frameworks (Zhou et al., 2016; Buccieri et al., 2020).

Source: The authors (2026)

This framework enables an integrated and scalable view of how knowledge engineering can serve as a cross-cutting infrastructure for SME internationalization. By explicitly linking KE instruments (e.g., semantic modeling, rule-based automation, digital profiling) with funding system dynamics, KE4SME-INT contributes to filling the persistent theoretical and methodological gap between international business and intelligent systems (Reynolds-Cuéllar et al., 2023).

Furthermore, KE4SME-INT is designed to be geographically and sectorially adaptable, allowing application in both high-tech and traditional industry settings, including Latin American cooperatives and European manufacturing SMEs. Its axes also serve as potential pillars for future benchmarking tools or self-assessment diagnostics aimed at SME funding readiness and digital maturity (Ginting, 2015; Symeonidou et al., 2017).

Figure 4 visualizes the interplay between these axes, forming a feedback-oriented loop where data, capabilities, and strategies continuously inform and refine each other.

6 CONCLUSION

This integrative review examined how small and medium-sized enterprises (SMEs) utilize digital technologies and knowledge engineering approaches to access international funding and innovation networks. Through a PRISMA-based methodology and semantic clustering of 124 peer-reviewed articles, the study identified prevailing technological strategies, key enablers of internationalization, and critical research gaps.

The findings demonstrate that the most impactful approaches combine structured knowledge management, digital platform integration, and the development of dynamic capabilities - particularly in relation to data literacy and absorptive capacity. While most empirical evidence centers on Chinese and European SMEs, Latin American cases - especially involving cooperatives - highlight the importance of localized, socially-embedded models of knowledge exchange and funding mobilization.

Despite the proliferation of digital tools, the literature remains fragmented. Few studies explicitly connect knowledge engineering methods with international funding success, and even fewer articulate frameworks that systematically integrate technological and organizational dimensions. This gap underscores the need for interdisciplinary bridges between international business, knowledge systems, and digital innovation.

6.1 Contributions

This review contributes to the literature by:

- Mapping the intersection of digital transformation, knowledge engineering, and SME internationalization;
- Proposing the KE4SME-INT framework, which integrates knowledge structuring, digital mediation, capability alignment, and funding access evaluation;
- Offering evidence-informed recommendations for policymakers, funding bodies, and SME stakeholders.

6.2 Liminations

The study relies on inferred metadata (e.g., country identification via title keywords) and excludes full-text semantic analysis, which may restrict the depth of contextual interpretation. Additionally, the review emphasizes peer-reviewed literature, potentially omitting relevant insights from grey literature or unpublished institutional evaluations.

6.3 Future Research Directions

To advance this field, future research should:

- Conduct comparative case studies applying the KE4SME-INT framework in real-world contexts;
- Explore automated systems for grant discovery using AI and semantic web technologies;
- Investigate regional innovation ecosystems and their role in mediating SME access to funding;
- Develop metrics to assess the effectiveness of KE-driven internationalization strategies, particularly in underrepresented regions such as Latin America and Africa.

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