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Technological Adaptation and TQM in Nanostores: Advancing Sustainable Development in Honduras

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Abstract*- This study examines how technological adaptation and Total Quality Management (TQM) foster innovation in nanostores—an essential yet under-researched segment of small-scale retail in emerging economies. Drawing on survey data from 143 nanostore managers in Honduras, cluster analysis reveals distinct adaptation behaviors and highlights TQM's mediating role in innovation. Findings support five hypotheses: (1) TQM enhances technological adaptation; (2) adaptation drives innovation; (3) nanostores form distinct adaptation clusters; (4) TQM mediates the adaptation–innovation link; and (5) clusters differ in innovation outcomes. Three adaptation profiles emerged—"Technology Leaders," "Pragmatic Adopters," and "Technology Laggers"—with higher innovation associated with more adaptive groups. From a Humanitarian Engineering perspective, nanostores function as nodes of inclusive innovation and community resilience. Integrating TQM with context-aware technologies provides a pathway for sustainable, scalable transformation. This research contributes to socio-technical systems theory in vulnerable settings and informs cross-sector strategies to support small retailers through participatory, quality-driven innovation. A strategic framework is proposed to guide future interventions. To strengthen generalizability, future research will expand to Colombia and Peru, offering cross-national insights that advance the goals of Humanitarian Engineering in Latin America.

***Keywords:* Technological Adaptation, Total Quality Management (TQM), Community Resilience, Humanitarian Engineering in Latin America (HELA), Inclusive Innovation.**

I. Introduction: Harnessing Quality and Technology for Community-Driven Retail Innovation

A. Background and Justification

Nanostores are key in emerging economies, providing access to essential goods, but face difficulties in adopting modern technologies such as point-of-sale systems and inventory management. Factors such as limited financial resources, lack of training and infrastructural constraints hinder their ability to compete with larger, more technologically advanced retailers.

Total Quality Management (TQM) offers a path forward, enhancing both efficiency and customer experience in ways particularly relevant for resource-limited retail actors [1]. However, its integration in nanostores, especially in relation to technological adaptation and innovation, has not been sufficiently explored. This research addresses a critical gap by shifting the focus from large-scale applications to the underserved domain of nanostores..

In vulnerable communities such as those in Tegucigalpa and San Pedro Sula, nanostores operate as informal food and service centers. Despite their community relevance, their lack of access to digital systems limits their capacity for growth and innovation. Improving their technologies and management is essential not only to modernize businesses but also to support livelihoods and promote inclusive development [2].

Rather than viewing them merely as small-scale businesses, this paper frames nanostores as dynamic community nodes—where local knowledge and bottom-up innovation meet adaptable technologies to solve real-world problems. Their transformation exemplifies how bottom-up innovation can thrive under constraints, catalyzing inclusive progress [2].

This paper aligns with the Humanitarian Engineering in Latin America (HELA) initiative by proposing participatory, context-aware strategies that bridge Total Quality Management (TQM) with inclusive technological adaptation. The goal is to support small-scale retail actors with frameworks that are not only strategic but community-anchored and scalable across Latin America.

To contextualize the key operational challenges and opportunities for these nanostores, Table I presents the core socio-technological characteristics relevant to this study.

TABLE I.
Socio-Technological Constraints and Opportunities

Characteristic	Description
Size	Small-scale, typically family-run operations with limited infrastructure
Technology Use	Primarily manual processes, limited to basic point-of-sale (POS) systems
Competitive Challenges	Pressure from larger retailers using advanced technologies (e.g., e-commerce)
Relevance of TQM	TQM could improve efficiency, customer service, and technology adaptation

[a] Own elaboration

B. Research Gaps in Technological Adaptation and TQM in Nanostores

While technological adaptation literature often centers on large organizations, it frequently overlooks the unique dynamics of informal, small-scale retailers like nanostores (defined as small, often family-run retail operations serving low-income communities, face systemic barriers). Embedded in low-resource, high-context communities, nanostores adapt technology not through standardized processes but via context-specific, community-driven methods. Their adoption of tools such as mobile payments, inventory apps, and WhatsApp-based customer service is shaped by immediate

needs and resource constraints, reflecting a bottom-up, participatory approach to innovation. This adaptability offers valuable insights into socio-technical integration in vulnerable communities, where flexibility and resilience are essential for survival. [3].

The Honduran context is particularly relevant for this study because its nanostores—often operating in informal, cash-dominant economies with fragmented supply chains—embody the systemic vulnerabilities that HELA seeks to address. Their reliance on interpersonal trust, limited access to digital tools, and exposure to competitive pressures from formal retailers mirror the broader challenges of inclusive development in Latin America. By focusing on Honduras, this research aligns with HELA's mission to co-design scalable, context-sensitive solutions that empower marginalized entrepreneurs through participatory technological and managerial innovation.

While existing research acknowledges the potential of TQM and technology for microenterprises, the intersection of these frameworks in the specific context of nanostores has not been empirically examined. This study explores how TQM can serve as a catalyst for technological adaptation and innovation in nanostores, with a focus on addressing several critical and previously underexplored research gaps:

1) Technological Adaptation in Nanostores: Limited research has explored how different nanostores adapt to emerging technologies, and the strategies they employ to overcome barriers to adaptation.

2) Role of TQM: Its application and impact on nanostores, especially in terms of technological adaptation, remain underexplored.

3) Clustering Adaptation Behaviors: No previous studies have applied cluster analysis to understand the heterogeneity of adaptation patterns in nanostores and how TQM influences them.

Through a structured approach, this research examines how TQM influences technological adaptation and its subsequent impact on innovation. It seeks to identify distinct adaptation clusters, evaluate the mediating role of TQM, and assess their impact on innovation outcomes.

This positions TQM not only as a business improvement tool but as a potential humanitarian enabler—bridging dignity, ownership, and inclusive participation.

Moreover, this research contributes to the HELA initiative by generating evidence-based recommendations for stakeholders—such as local governments, NGOs, and technical educators—on how to support inclusive technological transitions in informal and semi-formal economic units. The co-design process is central to equitable transformation—ensuring solutions that are viable, dignified, and grounded in lived realities.

C. Research Questions and Objectives

This study is driven by the following research questions:

1) What are the distinct patterns of technological adaptation behaviors exhibited by nanostores?

2) How do Total Quality Management practices influence these patterns of technological adaptation?

3) How do these patterns of adaptation contribute to innovation in the nanostore sector?

The main objectives of this study are:

1) To identify and classify clusters of nanostores based on their technological adaptation behaviors.

2) To examine how TQM practices affect technological adaptation within these clusters.

3) To assess the relationship between technological adaptation and innovation outcomes in nanostores.

Together, these objectives explore how TQM fosters adaptation, how adaptation fuels innovation, and how nanostores cluster around distinct behavioral patterns. These insights inform HELA-aligned strategies for inclusive, scalable, and participatory innovation..

Fig. 1 illustrates the conceptual framework guiding this study, showing how TQM practices—such as continuous improvement and employee engagement—create an environment conducive to technological adaptation in nanostores. This process drives innovation, enhances competitiveness, and links TQM with empowerment and inclusive innovation. The framework connects quality to equity and engineering to community agency, highlighting how small, low-tech systems can become innovation hubs when external interventions build on local capacities and encourage collective action[4].

Focusing on the Honduran context, this paper emphasizes the potential of adaptable, quality-driven models to foster equitable innovation and supports regional scaling and interdisciplinary collaboration for dignity-centered solutions in informal economies.

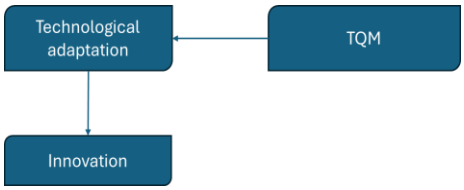

Fig. 1 TQM as a Driver of Tech Adaptation and Innovation in Nanostores

Thus, Section II presents the framework and hypotheses on TQM and technological adaptation in nanostores. Section III details the methodology, emphasizing data collection and cluster analysis to identify innovation profiles. Section IV reports the results, highlighting how adaptation and quality practices shape customer satisfaction in low-resource settings. Section V concludes with insights, implications for humanitarian engineering, and strategies to strengthen nanostore resilience through targeted innovation.

II. Enabling Inclusive Innovation in Vulnerable Retail Ecosystems: Humanitarian Engineering Perspective

A. Adaptive Technological Pathways for Nanostores in Underserved Communities

While technological adaptation literature has largely focused on large enterprises, nanostores—small retailers in underserved communities—remain underexplored. These businesses face systemic barriers like limited capital, digital illiteracy, and restricted access to scalable technologies [5].

Nanostores frequently adopt technology incrementally beginning with mobile payments and progressing toward inventory systems and customer tracking tools [6]. Unlike formal enterprises, these pathways reflect grassroots ingenuity and constrained optimization. This stepwise process, rooted in local conditions, makes nanostores ideal platforms for inclusive, bottom-up technological innovation [7].

Inclusive innovation addresses the needs of marginalized populations through co-creation, local relevance, and social empowerment. In this context, adaptation is social, influenced by trust and cultural fit. Nanostores, as co-creators of innovation, respond dynamically to their communities rather than relying on external solutions. Humanitarian engineering emphasizes enabling marginalized actors through participatory, locally rooted solutions. These adaptations often emerge from participatory dynamics, where nanostore owners, family members, and local customers co-develop strategies, reinforcing ownership, sustainability, and alignment with local knowledge.

B. TQM as a Humanitarian Enabler of Capability Building

TQM is an organizational philosophy focused on continuous improvement, employee engagement, and customer satisfaction. Within HELA-aligned frameworks, TQM acts as a tool for social and managerial empowerment, promoting collaborative learning, shared ownership, and the active engagement of nanostore owners. Its participatory approach reinforces quality as a community practice [9].

Here, continuous improvement transcends technical aspects, emphasizing social growth and collective empowerment, thereby enhancing the agency of small retailers through skill development, peer learning, and joint problem-solving [9]. TQM becomes not just a management tool, but a vehicle for inclusive innovation and context-specific capability building. Table II below summarizes key studies on technological adaptation and TQM in small retail environments, emphasizing the role of innovation, resource constraints, and community-driven solutions.

TABLE II.
KEY LITERATURE ON TQM AND TECHNOLOGICAL ADAPTATION

Author(s)	Year	Focus Area	Findings
[10]	2023	Digital tools in retail	Small retailers benefit from incremental technology adaptation.
[11]	2024	TQM in small enterprises	TQM improves operational efficiency and customer satisfaction.
[12], [13]	2017, 2023	Innovation in nanostores	Nanostores face unique barriers but can be innovated with tailored strategies.

[a] Own elaboration

C. Theoretical Foundations: Innovation, Resources, and Quality in Humanitarian Contexts

To frame the interplay between technology, quality, and innovation in nanostores, this study builds on four complementary theoretical lenses:

1) Diffusion of Innovation (DOI) Theory explains how innovations are adopted over time, from knowledge acquisition to implementation. For nanostores, adaptation is often non-linear and influenced by perceived value, cost, and simplicity [14].

2) Resource-Based View (RBV) emphasizes that sustained advantage emerges from unique and hard-to-imitate resources. For nanostores, resource constraints heighten the value of TQM practices that enhance human capital and improve resource utilization [15].

3) TQM serves as a bridge between strategic intent and execution. Through orientation process and customer-driven improvement, TQM can facilitate technological onboarding even in informal retail environments [16], [17].

4) Innovation in Small Enterprises recognizes that microenterprises face distinct institutional and financial barriers. Overcoming these often requires embedded support systems, peer learning, and simplified technologies—all of which are enabled by strong internal management practices like TQM [18].

In HELA contexts, innovative frameworks promote interdisciplinary collaboration by integrating engineering, management and social sciences. They reframe innovation as the cultivation of local capabilities, not just the importation of external tools. This holistic approach enables engineers, economists and community leaders to co-design specific solutions tailored to local constraints and opportunities..

D. Hypotheses on Humanitarian Systems and Context

Building on the theoretical foundations, this study formulates five hypotheses to examine how TQM and technological adaptation jointly influence innovation in nanostores. These hypotheses are tested through quantitative methods and validated using cluster analysis (see Table III).

TABLE III
HYPOTHESES ON TQM, TECH ADAPTATION, AND INNOVATION

Hypothesis	Expected Relationship	Supporting Literature
H1: TQM → Technological Adaptation	TQM practices positively influence technological adaptation in nanostores.	[19]
H2: Tech Adaptation → Innovation	Higher levels of technological adaptation led to increased innovation in products and services.	[20], [21]
H3: Clustered Adoption Behavior	Nanostores exhibit distinct patterns of technological adaptation, identifiable via cluster analysis.	[20]
H4: TQM as Mediator	TQM mediates the relationship between technological adaptation and innovation outcomes.	[17]
H5: Innovation by Cluster Type	Innovation levels vary by cluster, depending on the depth of TQM practices and technology use.	[22]

[a] Own elaboration

E. Cluster-Based Understanding of Nano-Retailer Behavior

Equity-driven segmentation by cluster analysis enables categorization of nanostores based on their technology usage patterns, allowing identification of typologies that vary by innovation level, operational efficiency, or resource constraints [23]. Fig. 2 illustrates this approach, visualizing the categorization of nanostores based on their technology adoption patterns. These clusters offer actionable insights for

tailoring HELA interventions to match the behavioral realities of each retailer group [17].

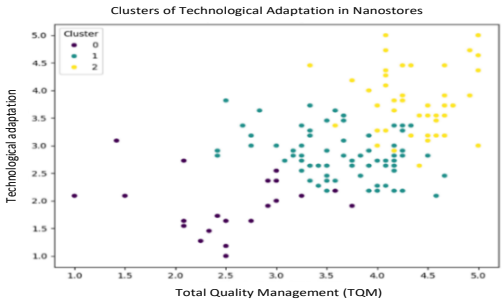

Fig. 2 Cluster Analysis of Nanostores' Technological Adaptation Patterns: Identifying Typologies for Targeted Support

Recognizing these behavioral clusters allows for targeted, context-aware interventions, a hallmark of humanitarian engineering.

F. Conceptual Model: TQM, Adaptation, and Innovation for Community Resilience

Fig. 3 presents the study's conceptual model, illustrating the synergistic relationship between TQM, technological adaptation, and innovation as key enablers of community resilience. The model emphasizes how TQM enhances the transformative potential of technology by embedding innovation into daily operational practices. This synergy creates a virtuous cycle of continuous improvement, where quality-driven processes and adaptive capabilities reinforce each other, sustaining innovation over time.

Rooted in the principles of Humanitarian Engineering, the model positions nanostores as active co-creators of development rather than passive recipients of aid or technology [24]. This co-creation fosters ownership and long-term impact, allowing nanostores to build responsive and inclusive supply chains [19]. It supports a bottom-up resilience approach, empowering micro-enterprises as catalysts for innovation and socio-economic transformation within vulnerable communities.

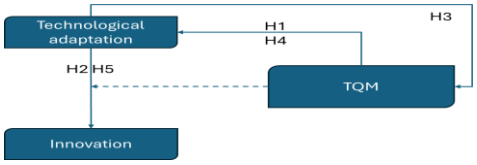

Fig. 3 Conceptual Framework for TQM-Driven Technological Adaptation and Innovation in Nanostores

G. Contributions to Humanitarian Engineering and Practice

This study contributes to both practice and theory in several ways:

(1) For nanostore owners and grassroots organizations, it highlights how TQM can serve as a cost-effective enabler of digital transformation—even in low-resource environments; (2) For policy makers and NGOs, it offers a roadmap for supporting micro-retailers through integrated interventions that combine quality improvement with simple tech tools; (3) For HELA stakeholders, it demonstrates how engineering principles can be humanized through managerial lenses, with active participation from beneficiaries and attention to the lived realities of vulnerable communities.

Ultimately, this study emphasizes not only what nanostores lack but also what they contribute—resilience, proximity, and localized intelligence—critical values in humanitarian engineering for inclusive development.

III. Methodology: Cluster-Based Analysis of Innovation Pathways in Nanostores

A. Research Design in Humanitarian Engineering Contexts

This study employs a quantitative research design grounded in the HELA framework, utilizing cluster analysis to examine how patterns of technological adaptation and TQM practices influence innovation outcomes in nanostores. Cluster analysis is an effective statistical method for identifying distinct adaptation behaviors among nanostores. Additionally, the study incorporates descriptive and inferential statistical techniques to analyze survey data and test the hypotheses outlined earlier.

In HELA-aligned contexts, where resources are limited and variability is high, such analytical approaches are essential to uncover bottom-up innovations and locally relevant clusters of practices.

Rationale for Cluster Analysis: Cluster analysis enables the identification of naturally occurring groups or clusters within the data without prior categorization. This is particularly useful in this research as the study aims to identify distinct patterns of technological adaptation behaviors and their corresponding innovation outcomes.

(1) Categorize nanostores based on their technological adaptation behaviors; (2) Investigate how TQM practices influence these behaviors; (3) Explore how these adaptation behaviors correlate with innovation outcomes in nanostores.

Cluster analysis, aligned with the HELA (Humanitarian Engineering in Latin America) framework, provides an empirical approach to understanding how community-grounded realities and inclusion-driven innovation strategies influence nanostore behaviors [20]. By identifying distinct adaptation patterns, this method supports HELA's goal of promoting equity through context-sensitive interventions. The insights gained not only inform policy development for small-scale retail sectors in vulnerable communities but also contribute to broader objectives of social empowerment and the reduction of structural inequalities within the retail sector.

B. Data Collection Process and Instrument Development

1) Literature Review: The first step in the research methodology was to conduct an extensive literature review to identify existing research on technological adaptation, TQM practices, and innovation in small retail businesses, particularly nanostores. This review helped to frame the theoretical foundation for the study, providing insight into how these factors have been examined in previous studies and establishing a gap in the literature regarding their intersection in the context of nanostores.

The literature review included academic sources from prominent databases such as Scopus, Web of Science, Emerald, and Springer. Keywords like "technological adaptation in small businesses," "TQM practices," and "innovation in retail" were used to gather relevant studies [21].

2) Development of the Expert Panel Instrument: Following the literature review, a panel of seven experts in operations management, small business innovation, and TQM was assembled. They evaluated key operational practices using a Likert scale from 1 (not important) to 5 (especially important) to develop a context-specific measurement instrument.

The feedback from the expert panel was used to refine the survey instrument and ensure it captured the key practices that influence technological adaptation and innovation in nanostores. A pre-test was conducted to ensure clarity and relevance, after which a definitive version of the survey was developed. Google Forms was chosen as the platform for the survey, allowing for efficient distribution and collection of data.

This step ensured cultural and contextual relevance—core to HELA's participatory design methodologies.

3) Survey Design: The final survey was designed to gather data on the following key variables:

(1) Technological Adaptation: Types of technology adopted, extent of use, and perceived benefits; (2) TQM Practices: Process standardization, employee involvement, and customer satisfaction; (3) Innovation Outcomes: Product/service innovation, customer experience, and business processes.

The survey was tailored to nanostores' realities, ensuring relevance to small retailers and their challenges. This methodological tailoring supports HELA's commitment to inclusive design and co-creation of knowledge with vulnerable stakeholders.[22].

C. Fieldwork Procedures and Ethical Framework

1) Survey Distribution and Sample: We employed purposive sampling to ensure representation across urban and rural nanostores in Honduras. The country was selected due to its high density of informal retail units, institutional interest in nanostore development, and active participation in HELA-aligned initiatives. Compared to countries like Guatemala or Nicaragua, Honduras presents a particularly acute combination of cash-dominant markets, fragmented supply chains, and limited access to digital tools—making it a critical site for inclusive innovation research.

The survey was administered to 143 proprietors or managers of nanostores in Honduras, selected from diverse locations to ensure representation. While relatively modest, the sample size of 143 is sufficient for cluster analysis and hypothesis testing. A post-hoc power analysis indicates acceptable power (0.8) for medium effect sizes in multiple regression and mediation models, in line with established guidelines for social science research.

Data collection was conducted through field-based coursework, with trained university students engaging local nanostore owners under faculty supervision. Participants were informed of the study's purpose, confidentiality rights, and voluntary participation. Informed consent was obtained. The 143 completed surveys—collected over a two-month period—met both quality and completeness criteria and were processed following ethical research standards.

2) Ethical Considerations: Measures were taken to ensure privacy and ethical integrity. Data was anonymized and securely stored. Participants could withdraw at any time. These procedures reflect HELA's emphasis on respectful, ethical partnerships with local communities.

D. Analytical Strategy: From Clustering to Mediation

1) Statistical Treatment of Data: Survey data were reviewed for consistency, with Cronbach's alpha assessing internal consistency (threshold: 0.70). K-means cluster analysis grouped nanostores by technological adaptation. The choice of K-means clustering was justified by its effectiveness in identifying distinct behavioral patterns in small sample sizes.

2) Linear Regression and Hypothesis Testing: Linear regression tested H1, confirming a positive relationship between TQM practices and technological adaptation. Stronger TQM practices correlate with quicker adoption of modern technologies, supporting HELA strategies for managerial training.

3) Cluster Analysis and Hypothesis Testing: K-means clustering tested H3, identifying clusters based on technological adaptation and TQM. One-way ANOVA revealed distinct behavioral clusters, guiding HELA interventions for inclusive innovation.

4) Mediation Analysis: Mediation analysis tested H4, showing that TQM mediates the relationship between technological adaptation and innovation, enhancing the effect of adaptation on innovation, supporting HELA's focus on organizational practices to catalyze innovation.

E. Summary: Toward Data-Informed, Inclusive Innovation

This study uses a combination of survey data and cluster analysis to test hypotheses on the relationships among technological adaptation, TQM practices, and innovation in nanostores. The methodology includes a rigorous process of data collection, instrument development, and statistical analysis to ensure validity and reliability. By identifying behavioral adaptation patterns, the study highlights how small retailers can become innovation agents—leveraging technology and quality management in line with HELA's inclusive goals for humanitarian engineering in Latin America.

TABLE IV
SUMMARY OF HELA-ALIGNED METHODOLOGY FOR NANOSTORE INNOVATION ANALYSIS

Step	Methodology/Analysis
Data Collection	Survey with 143 nanostore owners/managers.
Survey Instrument	Developed with input from expert panel and pre-tested.
Statistical Treatment	Cronbach's alpha for reliability analysis; cluster analysis for grouping.
Cluster Analysis	K-means clustering to identify groups of nanostores based on technology adaptation.
Hypothesis Testing	Linear regression, correlation analysis, cluster analysis, mediation analysis [25] to test for indirect effects, and one-way ANOVA.
Data Interpretation	Analyze how technological adaptation, TQM practices, and innovation outcomes are linked.

[a] Own elaboration. The methodology reflects HELA principles by combining participatory design, community engagement, and analytical rigor to support inclusive innovation.

IV. Empowering Micro-Retail Through Evidence: Results and Insights for Humanitarian Innovation

A. Data Overview and Descriptive Statistics

This study analyzes data from 143 nanostore owners and managers in Honduras through cluster analysis, ANOVA, and mediation techniques. The findings offer valuable insights for designing interventions aimed at strengthening resilience and promoting economic inclusion in vulnerable communities. We begin with descriptive statistics on key variables—technological adaptation, TQM practices, and innovation outcomes—to provide context before proceeding to hypothesis testing. .

1) Descriptive Statistics: Table V presents the descriptive statistics for technological adaptation, TQM practices, and innovation among respondents. The mean score for technological adaptation was 3.06, indicating moderate adoption of modern technologies. TQM practices had a mean score of 3.74, reflecting a relatively elevated level of implementation. Innovation outcomes scored 3.5, suggesting that most nanostores engage in innovation, with room for improvement.

TABLE V
Descriptive Statistics of Key Variables

Variable	Mean	Standard Deviation	Range (Min-Max)
Technological Adaptation	3.06	0.84	1 - 5
TQM Practices	3.74	0.57	1 - 5
Innovation Outcomes	3.5	0.85	1 - 5

[a] Own elaboration

These descriptive statistics provide a foundation for the subsequent analysis and hypothesis testing.

B. Hypothesis Testing: Pathways to Inclusive Innovation

1) TQM as a Catalyst for Technology Integration in Nanostores: H1 posited TQM practices influence technological adaptation in nanostores. To test this, a linear regression analysis was conducted with TQM practices as the independent variable and technological adaptation as the dependent variable. The results showed a significant positive relationship between TQM practices and technological adaptation ($\beta = 0.575$, $p < 0.001$), supporting H1.

These findings suggest that nanostores that implement higher levels of TQM practices are more likely to adopt modern technologies. This relationship reinforces the role of TQM as an enabler of operational modernization, especially in resource-constrained retail settings [26].

2) The Role of Technology in Driving Innovation Outcomes: H2 stated that technological adaptation positively influences innovation outcomes. To test this hypothesis, we conducted a correlation analysis between technological adaptation and innovation outcomes. The results showed a strong positive correlation ($r = 0.68$, $p < 0.001$), supporting H2.

This suggests that nanostores that adopt more advanced technologies tend to exhibit higher levels of innovation, particularly in product offerings and customer service. Technological adaptation appears to be a key driver of innovation in small retail businesses, likely because modern technologies enable more efficient processes and open new possibilities for innovation [27]. This aligns with HELA's emphasis on creating adaptable and scalable solutions for marginalized communities through technology, fostering sustainable business practices.

3) Mapping Diversity in Adaptation: Cluster Analysis for Targeted Support: There are distinct clusters of technological adaptation behaviors. H3 hypothesized that cluster analysis would reveal distinct patterns of technological adaptation behaviors in nanostores. To test this, we performed a k-means cluster analysis with the variables of technological adaptation and TQM practices. The optimal number of clusters was determined using the elbow method, which suggested three distinct clusters of nanostores.

Cluster 1: "Technology Leaders" – Stores in this cluster showed an elevated level of both technological adaptation and TQM practices.

Cluster 2: "Technology Adopters" – Stores in this cluster showed moderate levels of technological adaptation but still implemented some TQM practices.

Cluster 3: "Technology Laggers" – Stores in this cluster had low technological adaptation and relatively low engagement with TQM practices.

Fig. 4 presents the cluster analysis results, identifying three distinct groups based on technological maturity and TQM implementation. Unlike prior studies in similar contexts, our findings show that TQM practices differentiate stores even with comparable technological capabilities, underscoring a synergistic link between management practices and digital adaptation in resource-limited environments. These clusters reflect varying levels of technological integration and its influence on process optimization, confirming H3 and validating the cluster-based approach. The results offer actionable insights into equity-focused humanitarian interventions tailored to each cluster's specific capacities and constraints.

This classification provides insight into the heterogeneity of technological adaptation in the sector.

4) Strengthening the Link: TQM as a Mediator for Innovation Impact: TQM mediates the relationship between technological adaptation and innovation. H4 posited that TQM practices would mediate the relationship between technological adaptation and innovation outcomes. A mediation analysis was performed using the Baron and Kenny method [25] . The results indicated that TQM practices significantly mediated the relationship between technological adaptation and innovation (Indirect effect = 0.30, $p < 0.001$).

This suggests that technological adaptation positively impacts innovation, with robust TQM practices amplifying this effect. The mediation analysis shows how quality management enhances the innovation potential of technology adoption, emphasizing the need for coordinated efforts among businesses, communities, and policymakers—key to HELA's interdisciplinary approach. This supports HELA's advocacy for structural equity by highlighting how organizational capacity shapes technological empowerment [28].

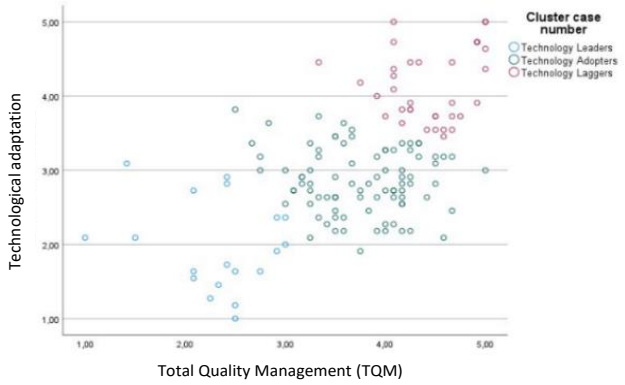

Fig. 4 Clusters of Technological Adaptation and TQM Practices

5) Understanding Innovation Disparities Across Adaptation Profiles: Clusters will exhibit various levels of innovation as shown in Table VI. H5 predicted that the clusters identified in H3 would exhibit varying levels of innovation outcomes. To test H5, we conducted an ANOVA test to compare the mean innovation scores across the three clusters. The results revealed significant differences in innovation outcomes between the clusters ($F(2, 140) = 44.402$, $p < 0.0001$). With 1 being the highest and 5 the lowest value for these considerations.

Cluster 1 (Technology Leaders) exhibited the highest innovation scores, with an average score of 2.5.

Cluster 2 (Technology Adopters) showed moderate innovation, with an average score of 3.4.

Cluster 3 (Technology Laggers) had the lowest innovative outcomes, with an average score of 4.2.

TABLE VI
INNOVATION OUTCOMES BY CLUSTER

Cluster	Mean Innovation Score	Standard Deviation
Technology Leaders	2.5	0.90
Technology Adopters	3.4	0.70
Technology Laggers	4.2	0.47

[a] Own elaboration

These results support H5, showing clear variations in innovation across clusters. Nanostores in the "Technology Leaders" cluster, adopting both advanced technologies and TQM practices, exhibit the highest innovation levels, while "Technology Laggers" show the lowest. This highlights the importance of combining technological adaptation and quality management in driving innovation, aligning with HELA's mission to use these tools for empowering underserved communities. It emphasizes the need for tailored interventions that foster sustainable, inclusive innovation in micro-retail ecosystems [29].

C. Synthesis of Results: Bridging Practice and Policy

Table VII confirms that TQM drives technological adaptation and innovation in nanostores, identifying three types of adaptation and their impact on results.

These data-driven insights offer actionable strategies grounded in humanitarian engineering. By identifying key leverage points—such as TQM-driven tech adoption—nanostores can become resilience nodes in vulnerable economies.

TABLE VII
SUMMARY OF HYPOTHESIS TESTING RESULTS

Hypothesis	Result	Interpretation
H1:	Supported	Positive relationship
H2:	Supported	Strong correlation
H3:	Supported	Three clusters identified
H4:	Supported	Mediation effect confirmed
H5:	Supported	Significant differences found

[a] Own elaboration

Aligning these practices with broader development goals, like those in the HELA framework, ensure benefits extend beyond individual businesses to enhance community resilience and sustainable growth. Policymakers should support small retailers with incentives, training, and resources to facilitate technology adoption and quality management. However, barriers like financial constraints, training gaps, and cultural inertia need to be addressed through cross-sector alliances. HELA promotes transdisciplinary partnerships to close these gaps.

V. CONCLUSIONS: ADVANCING INCLUSIVE INNOVATION THROUGH HUMANITARIAN ENGINEERING IN NANOSTORES

A. Empowering Innovation through Technology and Quality

This study examined how TQM and technological adaptation jointly enable innovation within the nanostore sector. Through a series of robust statistical analyses, including cluster analysis, regression analysis, and mediation tests, the research provides significant insights into the ways in which nanostores adopt technology, integrate quality management practices, and innovate.

The key findings from this study are as follows:

1) Technological Adaptation and TQM Synergies: We found that TQM practices positively influence technological adaptation in nanostores. This aligns existing literature on the importance of quality management in facilitating not only operational improvements but also technology adaptation [30]. The strong focus on quality improvement enhances the willingness and ability of nanostores to adopt and utilize modern technologies, thus improving their competitive edge, while contributing to localized economic resilience, a key pillar of humanitarian engineering in Latin America.

2) Innovation as an Outcome of Digital Inclusion: The research also demonstrated that technological adaptation is a significant driver of innovation outcomes. Nanostores that embrace technology tend to innovate more, whether through new products, services, or operational processes. This supports the notion that technological change is an essential pillar for innovation in retail businesses [3]. This further supports HELA's core strategy to use digital inclusion as a catalyst for inclusive innovation and localized economic transformation..

3) Cluster-Based Insights for Tailored Development: Using cluster analysis, we identified three nanostore clusters based on technological adaptation and TQM practices, ranging from "Technology Leaders" to "Technology Laggers." This novel perspective shows that nanostores adopt technologies differently, and these patterns significantly impact innovative outcomes. This segmentation allows for targeted interventions tailored to each group, supporting interdisciplinary strategies

that address the diverse challenges and capabilities within different community settings.

4) TQM as a Catalyst for Equitable Innovation: A key finding of the study was the mediating role of TQM practices in the relationship between technological adaptation and innovation. TQM practices not only enhance the direct effect of technology adaptation on innovation but also facilitate the implementation of more advanced technologies, leading to more impactful innovation [29]. This insight underscores the importance of integrating quality management into technology adaptation strategies in underserved areas where resource limitations are prevalent, reinforcing sustainable development goals and community empowerment.

5) Differentiated Innovation Outcomes across Nanostore Ecosystems: The study showed that nanostore clusters vary in innovation levels. "Technology Leaders" demonstrated the highest innovation, while "Technology Laggers" had lower outcomes. This emphasizes the need to combine technology adaptation with effective management practices to foster innovation. Targeted capacity-building for Technology Laggers can close innovation gaps, supporting HELA's vision of equitable, inclusive growth.

The findings on technological adaptation contribute to socio-technical integration by showing how technology adoption, supported by quality management, fosters cohesive ecosystems in vulnerable retail environments. These results enrich both academic and applied perspectives, demonstrating how TQM and technological adaptation drive innovation among vulnerable micro-retailers, aligning with HELA's goals for social impact.

B. Navigating Challenges: Limitations and Directions for Humanitarian Research

While this study provides valuable insights, several limitations must be acknowledged:

1) Sample Size and Generalizability: The analysis, based on data from 143 nanostores in Honduras, may not fully represent the diversity of nanostores across Latin America. A second phase of data collection—extending beyond Honduras to include Colombia and Peru—will enable cross-national comparisons and provide deeper regional insights. This expansion is essential for advancing HELA's mission of promoting context-sensitive innovation and understanding how micro-retailers in Latin America can leverage technology and quality management for inclusive growth.

2) Cross-Sectional Nature of the Data: The relationships identified are correlational, given the use of cross-sectional data. Longitudinal research is needed to unpack the temporal dynamics between TQM practices, technological adaptation, and innovation, especially in communities undergoing rapid socioeconomic change—a key concern in humanitarian engineering. The cross-sectional design limits causal claims—suggest longitudinal studies in future work.

3) Contextual and Cultural Differences: Cultural, economic, and infrastructural disparities may affect how nanostores engage with technology and quality practices. Comparative research across multiple humanitarian engineering contexts (e.g., post-conflict zones, refugee-supporting markets, or low-infrastructure urban areas) could yield a deeper understanding of the enabling and constraining conditions for innovation.

4) Unmeasured or Underexplored Variables: Factors such as leadership style, access to financial services, local cooperative structures, and community support mechanisms were not included in this study but may significantly shape innovation capacity. Future studies could integrate these variables and adopt participatory research methods to align with HELA's focus on active beneficiary involvement and co-creation with communities.

5) Interdisciplinary Approaches and Sustainable Technologies: In the spirit of HELA, future work should explore how low-cost sustainable technologies (e.g., solar-powered refrigeration, mobile POS systems) and interdisciplinary strategies (e.g., combining engineering, business, and social work) influence innovation in nanostores. A system-thinking perspective may also be beneficial for understanding how micro-level innovations scale up to impact broader community resilience and sustainability.

Self-reported bias is acknowledged but could triangulate with observational data.

Despite these limitations, the research provides a solid foundation for future studies. Future research could explore longitudinal designs to examine the long-term effects of TQM practices on technological adaptation and innovation in nanostores. Additionally, researchers could investigate the impact of external factors, such as market conditions or government policies, on the adaptation of modern technologies in small retail settings, particularly in developing countries with vulnerable populations.

C. Translating Findings into Action

1) Practical Implications: This research offers actionable recommendations for entrepreneurs, policymakers, and humanitarian practitioners working with vulnerable retail ecosystems:

Strategic Recommendations for Community Retailers: Nanostores should integrate TQM practices to enhance technological adaptation and innovation. TQM is essential for ensuring that technology investments lead to tangible improvements, potentially increasing job opportunities and economic stability in vulnerable regions. Policy and Capacity-Building for Marginalized Retailers: Policymakers and industry organizations can support nanostores through training programs on technological adaptation and quality management. Resources for transitioning Technology Laggers into more innovative operations could drive industry-wide improvements, while community-based training programs can integrate local knowledge with modern technologies, promoting economic development and social equity.

Adaptive Interventions for Distinct Innovation Clusters: The clustering of nanostores into distinct groups allows for more tailored interventions. For instance, Technology Leaders may benefit from further technological enhancements, while Technology Adopters might need support in fully integrating TQM practices to realize greater innovation potential. Tailored strategies could reduce disparities in access to technology and

empower marginalized communities by ensuring inclusive growth.

2) Theoretical Extensions of Dynamic Capabilities in Resource-Constrained Contexts: This research expands our understanding of RBV and dynamic capabilities in small businesses. By showing that TQM practices and technological adaptation enable innovation, the study contributes to knowledge on how small firms leverage internal and external resources, especially in humanitarian engineering contexts where adaptive capabilities are essential for inclusive development. The cluster analysis offers a new perspective on the diversity of technological adaptation behaviors in nanostores, providing a refined framework for understanding how these businesses approach technology and quality management. This heterogeneity is key for informing context-sensitive, inclusive interdisciplinary innovation approaches, advancing the humanitarian engineering agenda.

D. Local Economies, Global Agendas

The implications of this study extend beyond nanostores, touching broader economic and equity-driven development goals:

1) Strengthening Economic Resilience in Informal Markets: By promoting innovation through technological adaptation and TQM practices, nanostores can enhance their efficiency and competitiveness, leading to improved profitability and sustainability. The broader retail sector can benefit from more innovative small businesses, contributing to overall economic growth. Additionally, nanostores' role in local economies in vulnerable regions can be enhanced, leading to job creation and economic resilience in marginalized areas.

2) Enhancing Social Equity through Retail Innovation: Innovation in nanostores improves customer experience, efficiency, and access to quality products, benefiting local communities through improved services, employment, and entrepreneurship. In line with HELA, it fosters equitable access to modern retail technologies for all.

E. Contribution to Humanitarian Engineering and Development Studies

This paper's originality lies in applying advanced analytics to microenterprises, linking TQM, technology, and innovation through a humanitarian lens. By focusing on the often-overlooked small retail sector, it offers valuable insights for both academia and practice. The findings are especially relevant to small business owners and managers aiming to improve operations and innovate in a competitive retail environment, particularly within humanitarian engineering, where social development, sustainability, and collaboration are key to success.

F. Final Reflections: Empowering Innovation in Nanostores

This research shows how the interaction between TQM and technological adaptation drives innovation in nanostores. Through statistical analysis, innovation paths are identified based on technology access and organizational maturity. Within the framework of the HELA initiative, these findings highlight innovation in micro-retail as a driver of equity, sustainability, and community empowerment.

The cluster analysis offers actionable guidance for designing interventions that meet the specific needs of "Technology Laggers" and "Technology Leaders," promoting more inclusive development strategies. The findings also deepen theoretical understanding of dynamic capabilities and RBV in resource-constrained settings, positioning nanostores as adaptive systems capable of generating innovation despite limitations.

These contributions align with HELA's mission by emphasizing inclusive, interdisciplinary approaches to strengthening vulnerable retail ecosystems. We advocate for recognizing micro-retail innovation as a vital component of broader community resilience and development efforts.

Table VIII and Fig. 5 synthesize these contributions into a strategic framework aimed at enhancing resilience, competitiveness, and inclusivity across Latin America's retail landscapes.

TABLE VIII
SUMMARY OF CONTRIBUTIONS AND IMPLICATIONS

Contribution	Implication	Impact (Aligned with HELA)
Identification of distinct clusters of nanostores (Technology Leaders, Adopters, and Laggers)	Tailored support programs based on each cluster's technological and managerial maturity	Enables targeted development interventions and promotes inclusive innovation in vulnerable communities
TQM mediating the relationship between technology and innovation	Integrate TQM into national and local development programs to accelerate digital inclusion	Facilitates sustainable capacity-building and ensures technology leads to meaningful, context-sensitive innovation
Validation of the role of technological adaptation in microretail innovation	Justifies donor investments in digital infrastructure and training in underserved areas	Supports resilience-building in informal economies and aligns with SDG 9 and SDG 11
Theoretical contribution to RBV and dynamic capabilities in constrained settings	Refine existing theories with empirical insights from nanostores	Expands interdisciplinary innovation research and creates a foundation for future HELA-aligned studies

[a] Own elaboration

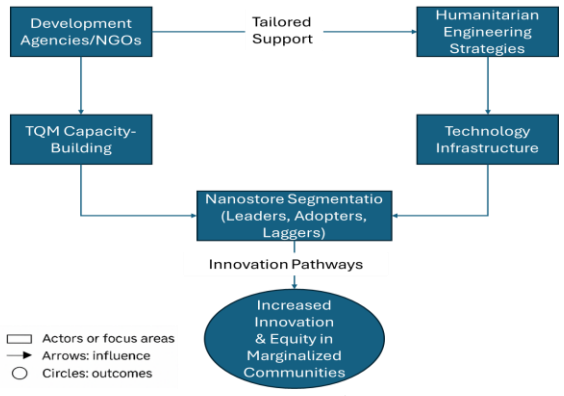

Fig. 5. Strategic Implications Framework for Nanostore Innovation

Table VIII provides actionable insights into policy and theory, while Fig. 5 maps the systemic interactions among key actors—nanostore owners, communities, policymakers,

NGOs, and technology providers—that drive inclusive innovation.

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