

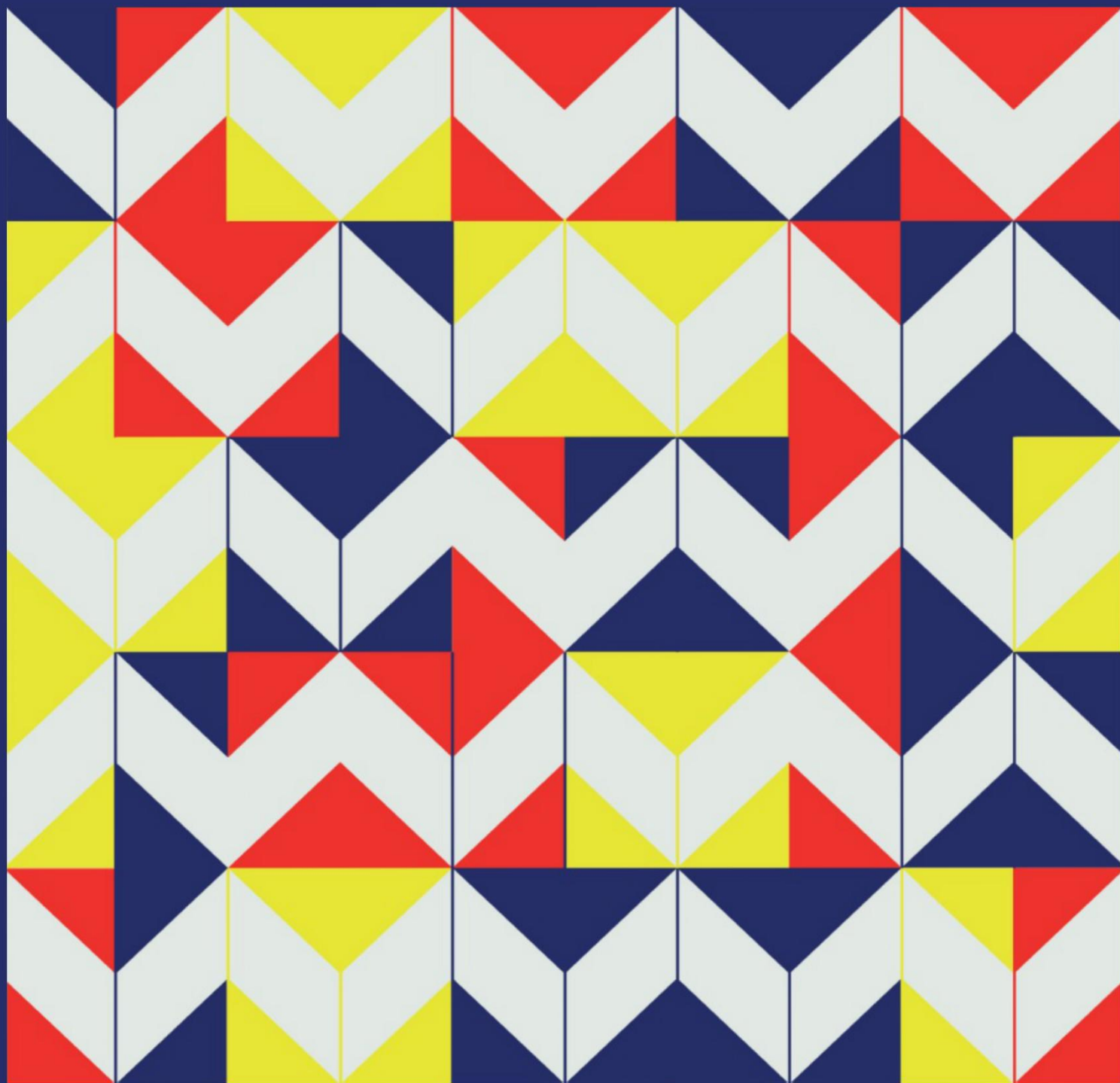
# Journal of Entrepreneurial Researchers

*If we never do it, we will never know*

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## Editorial Charter

The *Journal of Entrepreneurial Researchers (JER)* is a peer-reviewed, semiannual scientific journal published in digital open-access format by Ponteditora, Sociedade Unipessoal, Lda. JER is committed to advancing research in entrepreneurship and related fields by providing an international platform for the publication and dissemination of high-quality, original scientific contributions.

### Mission and Scope

JER aims to foster academic inquiry and global dialogue on topics central to the entrepreneurial research domain. The journal welcomes interdisciplinary, multidisciplinary, transdisciplinary, and pluridisciplinary approaches in areas such as the green and blue economy, eco-entrepreneurship, green accounting, sustainable finance, digital innovation, sustainability, and social inclusion.

Our mission is to promote excellence in entrepreneurial research, stimulate original thinking, and facilitate the exchange of ideas, experiences, and collaborative projects among scholars, professionals, and institutions worldwide.

### Language and Publication Format

JER publishes all content in English, accepting both American and British variants, as long as usage is consistent throughout the manuscript. Each article must include a title, abstract, and keywords. The journal publishes two issues per year, with each issue comprising approximately 80 to 180 A4 pages.

### Editorial Structure and Peer Review

The Editorial Team is composed of an international group of academics and professionals committed to scientific rigor and editorial independence. In addition to regular issues, JER also publishes special issues coordinated by guest editors with recognized expertise. All submissions undergo a two-stage evaluation:

1. **Desk Review** — Conducted by the Editor-in-Chief and Assistant Editors to assess alignment with the journal's scope and editorial standards.
2. **Peer Review** — Authors may choose between single-blind (anonymous reviewer), double-blind (default), or open peer review. In cases of conflicting evaluations, a third reviewer may be consulted.

All articles are selected based on relevance, scientific quality, and respect for diversity of perspectives.

### Ethical Standards

JER adheres to the highest standards of publishing ethics, drawing guidance from internationally recognized frameworks, including:

- Committee on Publication Ethics (COPE)
- World Medical Association's Declaration of Helsinki (WMA)
- International Committee of Medical Journal Editors (ICMJE)
- Animal Research: Reporting of In Vivo Experiments (ARRIVE)

The journal promotes integrity, transparency, and ethical responsibility throughout the publication process. Guidelines for Authors and Peer Reviewers are publicly available and regularly updated.

### Editorial Independence and Integrity

JER maintains full editorial independence and is free from political, ideological, or economic influence. The approval of manuscripts is guided strictly by academic merit, originality, and relevance to the field.

The Editorial Team also upholds the ethical principles enshrined in Article 17 of the Portuguese Press Law, ensuring journalistic good faith and responsibility toward readers.



### **Access and Inclusion**

JER is fully open access, offering free and unrestricted access to all its content. The journal actively promotes inclusivity and welcomes submissions from diverse geographic, institutional, and disciplinary backgrounds.

### **Final Note**

JER is a growing international platform committed to contributing meaningfully to the global conversation on entrepreneurship. Through rigorous peer review, ethical integrity, and a collaborative editorial culture, we aim to support the ongoing advancement of research and innovation.

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## Editorial—From closed science to open science, towards a human-centred ethos of innovation

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It is said that, one day, the mathematician Michael Atiyah tried to explain to his mother what it meant to be a researcher. She listened, smiled, and then asked: “Now I understand, my son—but why do they pay you to do that?” This anecdote, often recounted in academic circles, continues to illustrate the persistent gap between scientific work and the public perception of its value.

Although we recognise that knowledge is the true engine of progress, science remains largely confined to restricted circles. Since the seventeenth century, when the *Philosophical Transactions* first appeared, scholarly journals have played a crucial mediating role between knowledge and society. Yet the academic publishing ecosystem faces new dilemmas: metrics that overshadow meaning, the pressure to publish at all costs, and an increasing distance between scientific production and social utility.

If the twentieth century measured science by *impact*, the twenty-first must measure it by *meaning*—and by ethical coherence. This transition is embodied in the global movement towards Open Science. The policies of the European Union, particularly *Horizon Europe*, the *European Open Science Cloud (EOSC)*, and the *Knowledge and Innovation Communities (KICs)* of the EIT, have reshaped the scientific landscape. By promoting the principles of FAIR data (*Findable, Accessible, Interoperable, Reusable*) and Responsible Research and Innovation (RRI), Europe has placed openness, transparency, and human responsibility at the core of its research agenda. This transformation is not merely technical but profoundly cultural—redefining the relationship between the researcher, the institution, and society itself.

As articulated in the European Commission’s Open Science Policy Platform Report (European Commission, 2020) and the UNESCO Recommendation on Open Science (UNESCO, 2021), openness is not only a methodological demand but a cultural and ethical stance. It redefines science as a shared good — a collective endeavour grounded in transparency, inclusiveness, and epistemic justice. In this sense, the contemporary movement toward Open Science resonates with broader philosophical traditions that view knowledge as a relational and moral act (cf. Habermas, 1984; Merton, 1973), where truth gains legitimacy through dialogue, accessibility, and responsibility.

The *Journal of Entrepreneurial Researchers (JER)* actively embraces this epistemological turning point. Its mission is not only to disseminate rigorous, peer-reviewed research but to do so through an inclusive, interdisciplinary, and ethically grounded lens. Each issue seeks to bridge scientific excellence with social relevance, ensuring that entrepreneurial research contributes meaningfully to the broader human condition.

The present volume (Vol. 3, No. 2, 2025) is a landmark in this trajectory. It brings together six original contributions that collectively exemplify the transition from *closed science* to *open, responsible, and human-centred innovation*. More than discrete studies, these works form a mosaic of open scientific practices, where methodological diversity becomes a living dialogue between technology, ethics, and humanity.



## Highlights of Volume 3, Issue 2

### **1. Quantum-Enhanced AI Entrepreneurship in Tourism: Transforming Dynamic and Personalized Business Models**

*A. Salamzadeh, L.-P. Dana, M. Hadizadeh & N. Rastgoo*

The issue opens with a truly frontier contribution that integrates quantum-driven artificial intelligence with entrepreneurial strategy in tourism. Through simulations using twelve qubits, the authors construct an adaptive decision-making model capable of anticipating traveller preferences and responding to uncertainty in real time. This article positions *JER* at the frontier of global research on AI, sustainability, and digital transformation, demonstrating how quantum computing can reimagine entrepreneurship for complex and dynamic environments.

### **2. Ethics, Truth, and Values in Political Economy Research: Implications for Entrepreneurship and Innovation**

*A. M. R. Leite & M. V. de Vasconcelos*

This conceptual essay argues that ethics and values are not contaminants of scientific neutrality but its epistemic infrastructure. By integrating insights from philosophy, political economy, and entrepreneurship, the authors propose that the pursuit of truth in science inherently involves moral responsibility. Their contribution challenges reductionist models of value-free inquiry and positions ethics as a generative framework for responsible innovation and reflexive entrepreneurship.

### **3. Unpaid Work and Mental Health During a Pandemic: Evidence from the UK**

*M. V. de Vasconcelos, E. Santos, & R. D. Santos*

Drawing on longitudinal panel data from the *Understanding Society* survey in the United Kingdom, this study provides robust empirical evidence that the burden of unpaid work, especially domestic and caregiving tasks, significantly exacerbated mental health inequalities during the COVID-19 pandemic. Beyond the immediate findings, the article reveals the deep interconnection between social policy, well-being, and gendered labour structures—reinforcing the journal's commitment to addressing entrepreneurship as a social and human system.

### **4. Innovation in the Financial Sector: An Analysis of the Use of Blockchain Technology in Financial Institutions in Portugal**

*C. Lopes & R. Navas*

This empirical study examines the adoption of blockchain and decentralized finance (DeFi) within Portuguese financial institutions. Based on a survey of 168 respondents, the authors identify how these technologies can enhance transparency, trust, and efficiency while reshaping the competitive landscape of banking and investment. The research highlights how digital transformation in finance aligns with the open-innovation paradigm, encouraging regulatory agility and institutional resilience.

### **5. Entrepreneurial Innovation through Quality Function Deployment: From Customer Voice to Measurable Design in a Ready-to-Eat Taro Product**

*M. Teles*

At the intersection of engineering, sustainability, and entrepreneurship, this paper introduces an ISO 16355-aligned framework that translates the Voice of the Customer (VoC) into measurable design and production parameters—such as pH, shelf life, oxygen transmission rate (OTR), water vapor transmission rate (WVTR), percentage of recycled content, and supplier certification standards. The study not only operationalises the concept of sustainability beyond declarative claims but also provides a replicable blueprint for responsible innovation and *Stage-Gate* governance in food entrepreneurship.



## 6. Technological Innovation and Management in Rehabilitation Nursing

G. Jardim (ISCTE)

Closing the issue, this article explores the integration of technological innovation into rehabilitation nursing, bridging clinical practice, academic entrepreneurship, and strategic management. Through comparative analysis of international reference systems (Mayo Clinic, Cleveland Clinic, KiReS) and national initiatives such as *DigiNurse* and *TecCare*, the study reveals how technology can personalise care, improve outcomes, and humanise healthcare systems. It stands as a compelling demonstration of how entrepreneurial and academic collaboration can deliver measurable, sustainable benefits to society.

### Conclusion

Across these six studies—spanning quantum intelligence, ethics, social well-being, financial technology, sustainable design, and healthcare innovation—this issue embodies the guiding principle of the *Journal of Entrepreneurial Researchers*: that science achieves its highest purpose when it serves humanity. Entrepreneurship is thus not merely an economic function, but a dynamic synthesis of ethics, technology, and social value.

By publishing this collection, the *JER* reaffirms its commitment to a human-centred ethos of innovation, fully aligned with the European Research Area, the Open Science movement, and the frameworks of Responsible Research and Innovation (RRI). The journal seeks to advance knowledge that is both rigorous and transformative—knowledge that connects discovery with meaning, and innovation with dignity.

### Editorial Note (2026): Commitment to Triple-Blind Peer Review

Beginning in 2026, the *Journal of Entrepreneurial Researchers* will progressively implement a triple-blind peer review system, ensuring that authors, reviewers, and handling editors remain mutually anonymous during the evaluation process. This initiative strengthens the journal's commitment to equity, diversity, and research integrity, fully in line with the Committee on Publication Ethics (COPE) and the DOAJ Best Practices 2025.

### Positioning Statement

This editorial represents not only the introduction of Volume 3, Issue 2, but also the consolidation of *JER* as an emerging European and global platform for open, interdisciplinary, and responsible research in entrepreneurship and innovation.

It directly reflects the journal's adherence to Scopus and Web of Science selection criteria: regular publication continuity, international author diversity, strong ethical and editorial standards, thematic relevance, and visible engagement with contemporary research policies such as Open Science, FAIR data, and RRI.

The growing international recognition of the *Journal of Entrepreneurial Researchers* is also reflected in its distinguished author and editorial network. Volume 3, Issue 2 includes a contribution by Leo-Paul Dana, listed among the world's Top 2 % most-cited scientists according to Stanford University's global classification, whose seminal work on entrepreneurial ecosystems and cross-cultural entrepreneurship continues to inspire the field worldwide.

The editorial board likewise features David B. Audretsch, another Top 2 % Stanford scholar and one of the founding architects of the modern research agenda in innovation and regional development; Vanessa Ratten, also ranked in the Top 2 %, globally recognised for pioneering studies in entrepreneurial learning, sports entrepreneurship, and social innovation; and Dafna Kariv, a leading voice in entrepreneurship education, women's leadership, and gender-inclusive innovation policy.

Collectively, their involvement reflects *JER*'s ability to bridge continents, generations, and perspectives — integrating economic, social, and humanistic dimensions of entrepreneurship. Their participation attests to the journal's scientific maturity and reinforces its commitment to excellence, mentorship, and the dissemination of



knowledge that transcends borders. Together, these affiliations demonstrate JER's capacity to unite emerging and established scholars in a genuinely international dialogue — a core criterion of the Scopus and Web of Science selection frameworks.

By uniting scientific excellence with accessibility and societal value, the *Journal of Entrepreneurial Researchers* stands as a reference for the new generation of academic publishing—one where knowledge is not only produced but meaningfully shared, reinforcing the conviction that innovation, when centred on the human being, is the most enduring form of progress.

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### Ethical Statement

**Conflict of Interest:** Nothing to declare. **Funding:** Nothing to declare.



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# Quantum-enhanced AI entrepreneurship in tourism: Transforming dynamic and personalized business models

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## Abstract

This research integrates quantum-driven artificial intelligence with innovative entrepreneurial strategies to design an adaptive decision-making model for tourism businesses. The model leverages principles of quantum uncertainty and artificial intelligence to address operational complexity and uncertainty, advancing personalized traveler experiences and sustainable tourism entrepreneurship. Through theoretical synthesis and simulations using twelve qubits, the study models key variables—including tourist preferences, real-time conditions, economic and health indices, social media trends, and resource capacities—to optimize tourism management and entrepreneurial decision-making. Results illustrate enhanced adaptability, resilience, and business innovation by supporting entrepreneurial actions such as personalized travel planning, supply chain optimization, crisis response, and business opportunity prediction. The findings propose quantum-AI integration as a disruptive force within tourism entrepreneurship, promoting both sustainable business models and global industry transformation.

**Keywords:** Digital Innovation; Quantum Artificial Intelligence; Tourism Entrepreneurship.

## 1. Introduction

The tourism industry has rapidly solidified its position as a critical driver of global economic growth and employment (Sagar, 2024). According to the World Travel & Tourism Council (WTTC), the sector contributed an unprecedented \$11.7 trillion to the global economy in 2025, constituting over 10.3% of the world's gross domestic product (GDP) and supporting 371 million jobs worldwide—more people than the entire population of the United States (Hudson, 2025; WTTC, 2025). Projections indicate that by 2034, tourism's economic impact will reach \$16 trillion, accounting for more than 11% of global GDP, underscoring the sector's robust potential and its continued resilience despite challenges like the COVID-19 pandemic (World Economic Forum, 2025; WTTC, 2025). This growth reflects not only recovery but structural transformations and diversification within the industry, driven by new traveler demographics, emerging markets, and technological advancements (GSTC, 2025).

Tourism's dynamic nature stems from its inherent complexity as a multidisciplinary system governed by intertwined human, economic, cultural, and environmental factors (Farsari, 2023). The sector is marked by nonlinear behavior, sensitivity to initial conditions, and high unpredictability due to influences such as climate change, geopolitical shifts, economic fluctuations, and public health crises like the recent pandemic (Shahzad et al., 2022). Moreover, the rapid dissemination of information through social media and digital platforms continually reshapes traveler expectations, behaviors, and cultural values, generating diverse and evolving demands that tourism businesses must adeptly meet (Swadhi et al., 2025).



This increasing complexity challenges traditional linear decision-making frameworks that assume stability, predictability, and separability of factors (Shevchenko & Petrushenko, 2022). Classical models struggle to capture the multifaceted, volatile interactions that characterize the contemporary tourism eco-system, especially amid growing environmental and social sustainability concerns (Pinhal et al., 2025). The necessity for more sophisticated, adaptive, and data-driven decision-making approaches is paramount to empower tourism entrepreneurs and businesses to navigate uncertainty, seize new market opportunities, and implement resilient growth strategies (Stylos et al., 2021).

Quantum mechanics, with its foundational principles such as uncertainty, superposition, and entanglement, offers an avant-garde theoretical lens to analyze and manage complex systems exhibiting chaotic and nonlinear behaviors (Sandua, 2024). Unlike classical frameworks, quantum theory allows simultaneous representation and interaction of multiple states, providing a more nuanced and potent mathematical foundation for modeling interdependent variables and complex interactions prevalent in tourism systems (Khodair, 2024). Leveraging these quantum phenomena facilitates innovative computational paradigms that transcend traditional limitations in scope and scalability (Khurana et al., 2024).

By integrating quantum mechanics with artificial intelligence (AI), particularly through machine learning and deep learning, this study proposes a transformative framework capable of dynamic, real-time processing and interpretation of multifaceted tourism data streams (Paramesha et al., 2024). This quantum-AI synergy enables intelligent, adaptive decision-making that simultaneously considers heterogeneous variables such as tourist preferences, environmental conditions, economic indicators, social media trends, and resource capacities (How & Cheah, 2024). The use of a 12-qubit quantum circuit in this study exemplifies the ability to capture multi-dimensional complexity efficiently, facilitating enhanced prediction accuracy, optimization of tourism supply chains, crisis resilience, and personalized service delivery.

From an entrepreneurial perspective, such quantum-driven AI frameworks open new frontiers for innovation and business model transformation within tourism (Denis et al., 2025). They empower entrepreneurs to cultivate flexible, customer-centric offerings, optimize operational efficiency, and enhance market responsiveness in ways unattainable through classical computational methods alone (Cuomo & Foroudi, 2025). This study underscores the increased potential for data-driven entrepreneurial ventures to generate differentiated value propositions and foster sustainable competitive advantages amid the evolving global tourism landscape.

The objectives of this research are twofold: first, to develop an AI-powered decision-making model embedded with quantum computational principles for the tourism industry; and second, to demonstrate the model's practical applicability across diverse entrepreneurial scenarios including personalized tour planning, management of destination capacities, real-time crisis adaptation, and proactive market insights. By doing so, the study sets a precedent for leveraging quantum AI innovation as a key strategic asset for progressive tourism entrepreneurship and intelligent service management.

This research contributes to the frontiers of entrepreneurial knowledge and practice by merging disciplines of quantum physics, AI, and tourism management into a cohesive decision-making paradigm. It offers a visionary pathway toward resilient, sustainable, and innovative tourism businesses and underscores the critical role of emerging technologies in shaping the future of global tourism economies.

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## 2. Literature Review

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### 2.1. Quantum Mechanics and Artificial Intelligence in Complex Systems

Quantum mechanics, as a foundational framework of modern physics, offers a novel theoretical foundation and profound insights for analyzing and managing complex, nonlinear systems characterized by uncertainty, dynamic interactions, and multifaceted behaviors (Raza, 2024). Unlike classical physics, which relies on deterministic and linear models, quantum mechanics introduces key principles such as uncertainty, superposition, and entanglement, enabling the simultaneous representation and processing of multiple states within a system—capabilities that surpass the limits of classical computation (Saluja, 2025; Yazdi, 2024). Complementing this,

artificial intelligence (AI), particularly through machine learning and deep learning algorithms, excels at extracting patterns and making adaptive decisions from vast data sets (Rane et al., 2024). The fusion of quantum mechanics and AI, known as quantum AI, has thus emerged as a transformative approach for tackling highly complex, multidimensional problems across various domains, enhancing decision-making accuracy and flexibility—an essential advancement for industries facing unpredictable and multifaceted scenarios (Quadrat-Ullah, H., 2025).

One of the foundational aspects of quantum mechanics relevant to complex systems is the uncertainty principle, which postulates fundamental limits on the precision with which pairs of physical properties can be known simultaneously (Aerts et al., 2025). This principle is directly applicable to modeling environments where variables continuously fluctuate and influence each other in unpredictable ways, such as tourism ecosystems affected by shifting economic, environmental, and social factors (Vuong & Nguyen, 2024).

Superposition allows quantum states to exist in multiple configurations at once, providing a powerful means for considering all possible scenarios in complex decision-making processes simultaneously (Youvan, 2024). This is especially valuable in domains characterized by multifactorial dependencies, where traditional models struggle to cope with the sheer combinatorial explosion of possibilities (Khurana et al., 2024). Further, entanglement establishes correlations between disparate elements of a system that classical models cannot explain, enabling holistic and more accurate system representations (Srivastava et al., 2024).

In recent years, artificial intelligence (AI) has emerged as a complementary technology to quantum mechanics in addressing complexity and uncertainty (Ahmadi, 2023). AI's strength lies in its ability to process large-scale data, recognize hidden patterns, and generate adaptive responses using algorithms such as machine learning and deep learning (Wilson & Anwar, 2024). However, classical AI approaches still face limitations in modeling highly complex, nonlinear systems with multi-dimensional variable interactions (Tang et al., 2024).

The integration of quantum mechanics principles both theoretically and computationally with AI has given rise to quantum artificial intelligence (quantum AI), which promises enhanced problem-solving capabilities (Pappas, 2025). Quantum AI leverages quantum computing's ability to perform parallel processing exponentially faster than classical computers, allowing for efficient handling of complex datasets and systems (Padmanaban, 2024). This synergy is critical for domains like tourism management where rapid and simultaneous analysis of multiple variables—such as tourist preferences, real-time environmental conditions, economic indicators, and social trends—is necessary for dynamic and personalized decision-making (Gharib & Gahi, 2025).

Current developments in quantum AI demonstrate its potential for revolutionizing complex system management by providing models that are not only computationally efficient but also structurally capable of capturing the intrinsic uncertainty and interaction dynamics (Khurana et al., 2024). For example, quantum machine learning algorithms exploit superposition and entanglement to optimize learning accuracy and speed, compared to their classical counterparts, making them well-suited for adaptive, real-time applications (Ullah & Garcia-Zapirain, 2024).

The literature thus establishes a solid theoretical and applied foundation for leveraging quantum mechanics integrated with AI in addressing complex systems typically marked by uncertainty, dynamism, and multidimensional interdependencies—characteristics central to the tourism industry's operational landscape. This interplay between quantum theory and AI lays the groundwork for developing advanced decision-making models that serve innovative, resilient, and adaptive entrepreneurial ecosystems in tourism.

## **2.2. Application of AI in Tourism Management and Entrepreneurship**

Artificial intelligence (AI) has become an indispensable component in the transformation of tourism management and entrepreneurship, driving a shift from traditional operational models to digitally enabled, intelligent systems that respond to the increasing complexity and dynamism of global travel markets (Bondarenko et al., 2025). AI-driven tools such as chatbots, virtual assistants, and neural networks are widely



adopted to optimize operations, enhance personalization, and improve customer service experiences. These technologies support critical functions including demand forecasting, dynamic pricing, and customized travel recommendations (Nwabekee et al., 2025). By enabling tourism entrepreneurs to develop customer-centric business models and agile strategies, AI facilitates effective responses to fluctuating market conditions and evolving consumer preferences (Kumar, 2025). Furthermore, the integration of AI fosters social innovation within the tourism sector, contributing to sustainable growth and improved visitor engagement (Srinivasan et al., 2024).

One of the most widely adopted AI applications in tourism is predictive analytics. Machine learning algorithms analyze historical and real-time data to forecast tourist demand, optimize pricing strategies, and manage supply chain logistics (Ghodake et al., 2024). These forecasting abilities allow tourism entrepreneurs to proactively adjust their offerings, enhance resource allocation, and mitigate risks linked to volatile market conditions, health crises, or geopolitical instabilities (Iriani et al., 2024). Such precision forecasting has become critical in ensuring resilient and flexible business operations, a necessity underscored by recent disruptions like the COVID-19 pandemic (Kasali, 2025).

Personalization and customer experience enhancement constitute another significant domain where AI proves transformative (Rinne, 2025). Technologies such as AI-powered recommendation systems, chatbots, and virtual assistants enable tailored travel suggestions matching individual preferences, budgets, and contextual factors, thereby driving customer satisfaction and loyalty (Nugroho et al., 2024). For example, AI systems can dynamically adjust travel itineraries based on real-time environmental conditions or user feedback, offering adaptive and personalized services that differentiate entrepreneurial ventures in highly competitive markets (Panda & Khatua, 2025).

In the context of entrepreneurship, AI empowers new and established tourism businesses to innovate beyond classical service delivery models (George & Mattathil, 2025). By harnessing AI's capabilities in data mining and customer behavior analysis, entrepreneurs gain actionable insights to identify market gaps, optimize marketing strategies, and design novel products that resonate with evolving tourist demands (Usman et al., 2024). AI's role in business intelligence thus facilitates entrepreneurial agility and strategic innovation, key components for sustainable competitive advantage in the tourism industry (Isibor et al., 2025).

Moreover, AI contributes to sustainable tourism practices by optimizing resource use and minimizing environmental impacts (Patrichi, 2024). Smart tourism platforms integrate AI algorithms for efficient energy management, waste reduction, and congestion control, aligning with global sustainability goals and responsible tourism paradigms (Topsakal, 2025). This sustainability focus not only enhances community acceptance but also attracts environmentally conscious travelers, broadening market reach and reinforcing positive brand identity for tourism entrepreneurs (Khan et al., 2024).

Several case studies highlight the successful implementation of AI in entrepreneurial tourism ventures worldwide (Filiari et al., 2021). For instance, AI-driven smart destination management systems optimize visitor flows, facilitate crowd control, and enhance safety without compromising visitor experience, demonstrating how innovative entrepreneurial initiatives can address complex operational challenges (Vetrivel et al., 2025). Similarly, AI-based sentiment analysis of social media enables entrepreneurs to monitor destination reputation, respond swiftly to market trends, and engage more effectively with target audiences (Roy, 2025).

Despite these advancements, challenges remain in integrating AI within tourism entrepreneurship (Filiari et al., 2021). Issues such as data privacy concerns, high initial investment costs, and insufficient technical expertise often hinder widespread adoption, especially among small and medium-sized enterprises (SMEs) (Schönberger, 2023). Addressing these barriers requires collaborative efforts from policymakers, technology providers, and industry stakeholders to create supportive ecosystems for AI innovation in tourism entrepreneurship (AL-Romeedy & El-Sisi, 2024).



AI's application in tourism management and entrepreneurship represents a dynamic frontier for innovation, enabling stakeholders to navigate complexity with enhanced decision-making, personalized services, and sustainable growth strategies (Vinod et al., 2025). This literature establishes AI as a vital enabler of entrepreneurial resilience and competitiveness in the evolving tourism landscape, providing a crucial foundation for the integration of quantum AI approaches explored in this study.

### **2.3. Quantum AI Advances and Their Potential in Tourism**

Recent studies highlight quantum artificial intelligence (Quantum AI) as a groundbreaking convergence of quantum computing principles with artificial intelligence technologies, offering unprecedented computational capabilities poised to transform diverse industries, including tourism (Ahmadi, 2023). By integrating core quantum mechanics features such as superposition, entanglement, and quantum parallelism with advanced AI algorithms, Quantum AI delivers enhanced problem-solving, optimization, and pattern recognition abilities that surpass the limits of classical computing (Eswaran et al., 2025). This allows Quantum AI models to analyze multiple interacting variables simultaneously, enabling real-time decision-making and improved scenario planning (Dixit, 2022). Such capabilities are particularly valuable for managing complex tourism ecosystems by optimizing supply chains, regulating destination capacities, and enhancing crisis resilience (Rane et al., 2024). The pioneering use of quantum AI circuits in tourism entrepreneurship marks a new frontier for developing adaptive, dynamic, and sustainable business models (Khang & Rath, 2024).

At the core of quantum AI's relevance to tourism lies its ability to efficiently process and analyze vast, complex datasets characterized by high dimensionality and uncertainty—a hallmark of tourism ecosystems (Shuai & Karia, 2024). Quantum circuits leverage superposition to represent multiple possibilities simultaneously, enabling accelerated evaluation of numerous scenarios for decision-making (Indrajit, 2024). This capacity is particularly advantageous for dynamic and complex environments such as tourist destinations, where multiple interdependent variables (Cuomo & Foroudi, 2025)—including visitor preferences, environmental conditions, economic factors, and real-time crises—must be concurrently considered (Thirupathi et al., 2024).

Recent theoretical advances emphasize the application of quantum machine learning models such as quantum support vector machines, quantum neural networks, and quantum reinforcement learning for optimizing tourism-related functions (Núñez et al., 2024). These include personalized itinerary recommendations, adaptive resource management, destination capacity forecasting, and crisis response strategies (Bethune et al., 2022). For example, quantum reinforcement learning algorithms can dynamically adapt tourism service offerings by learning from feedback and changing patterns faster than classical algorithms, thereby enabling entrepreneurs to rapidly innovate in service delivery (Şeker, 2023).

Moreover, quantum AI's built-in ability to handle entangled states allows it to encapsulate complex systemic correlations—such as those among environmental sustainability measures, economic impacts, and social factors—that classical approaches often overlook or oversimplify (Brin, 2022). This holistic comprehension supports the development of more resilient, context-aware business models that can thrive amid turbulent market conditions and multifaceted stakeholder demands (Jennings, 2024).

While still exploratory, early implementations of quantum-inspired algorithms have demonstrated promising applications in simulating tourism supply chains and optimizing operational logistics (Núñez-Merino et al, 2024). These pilot studies reveal potential gains in efficiency, cost reduction, and adaptability—crucial elements for entrepreneurial success and sustainable growth in competitive tourism markets (How & Cheah, 2024).

However, the full practical adoption of quantum AI in tourism faces notable challenges (Talukder et al., 2025). Scalability constraints, quantum hardware accessibility, error rates, and the nascent state of domain-specific quantum algorithms require ongoing research and development (Sepulveda et al., 2024). Interdisciplinary collaboration among quantum physicists, AI specialists, and tourism entrepreneurs is essential to translate quantum AI theoretical potential into tangible industry innovations (Khang & Rath, 2024).



Despite these obstacles, the enormous promise of quantum AI for revolutionizing tourism entrepreneurship lies in its transformative approach to handling complexity, uncertainty, and multi-layered decision-making (Özsungur, 2024). As the technology matures, quantum AI has the potential to underpin the next generation of smart tourism solutions that combine cutting-edge computational power with entrepreneurial agility and sustainable innovation, positioning the tourism sector at the forefront of digital and quantum-driven economic growth (Fatema et al., 2024).

### ***2.3.1. Comparing Quantum AI and Classical AI for Tourism Applications***

While classical AI techniques including machine learning and deep neural networks have been instrumental in tourism for tasks such as demand forecasting, personalized recommendations, and operational optimization, quantum AI introduces a fundamentally different computational paradigm that promises to advance capabilities in several key areas (Vaissnave et al., 2024).

Quantum AI leverages quantum superposition and entanglement to process multiple interacting variables simultaneously, allowing for a natural parallelism in evaluating complex, nonlinear, and interdependent tourism scenarios (Pappas, 2025). This contrasts with classical AI, which typically analyzes scenarios sequentially or relies on approximations for multi-scenario analysis, often incurring higher computational costs as complexity grows (Ahmadi, 2023).

In practical terms, quantum AI has the potential to enhance the efficiency and accuracy of optimization problems critical to tourism entrepreneurship, such as dynamic pricing, adaptive routing, and crisis scenario planning, by exploring vast solution spaces more effectively (Sonavane & Aylani, 2025). However, these advantages remain largely theoretical or constrained by current quantum hardware limitations typical of the NISQ (the Noisy Intermediate-Scale Quantum) era (Lau et al., 2022).

While classical AI currently offers more mature, scalable, and reliable solutions for many tourism applications (Fileri et al., 2021), ongoing progress in quantum algorithms, hybrid quantum-classical methods, and hardware development provides a pathway for quantum AI to complement and potentially surpass classical approaches (Acampora et al., 2025), particularly in handling highly complex, multi-variable decision environments with inherent uncertainty (Thompson, 2021).

This distinction underscores the importance of adopting hybrid frameworks that combine the strengths of both classical and quantum computing to tackle the pressing challenges and opportunities in tourism innovation today.

## **2.4. Digital Innovation Transforming Tourism Business Models**

Digital innovation has increasingly emerged as a transformative force reshaping tourism business models, fundamentally altering how entrepreneurial ventures operate, engage customers, and create value (Santarsiero et al., 2024). Central to this transformation are advanced technologies such as artificial intelligence (AI), big data analytics, the Internet of Things (IoT), and blockchain, which empower tourism entrepreneurs to deliver innovative services, optimize operations, and respond agilely to evolving market demands (Paramesha et al., 2024). This shift toward data-driven decision-making enables the design of personalized travel experiences and efficient resource allocation, enhancing both operational effectiveness and customer satisfaction (Onesi-Ozigagun et al., 2024). Moreover, digital platforms and AI tools foster collaborative networks, cultural entrepreneurship, and social inclusion initiatives, aligning with the global emphasis on sustainable and responsible tourism development championed by the Journal of Entrepreneurial Researchers (JER) (Moghadasnian, 2024).

One of the profound ways digital innovation is influencing tourism business models is through data-driven personalization. AI-powered algorithms analyze large datasets on traveler behavior, preferences, and feedback to craft individualized travel experiences, enabling businesses to differentiate themselves in highly competitive markets (Kumar et al., 2025). This customized approach goes beyond traditional segmentation by dynamically

adapting offers and services in real-time, enhancing customer satisfaction and loyalty (SONI, 2025). For entrepreneurs, such technological capabilities open avenues for value co-creation, increased customer lifetime value, and stronger market positioning (Solakis et al., 2024).

Digital platforms are also facilitating new collaborative and participatory business ecosystems in tourism (Schuhbert et al., 2024). Online marketplaces, social networks, and sharing economy platforms empower entrepreneurs to access wider customer bases and deploy innovative business models such as peer-to-peer accommodations, community-based tourism, and experiential travel services (Rathnayake & Roca, 2025). These platform-based models reduce entry barriers and transaction costs, enhancing opportunities for small and medium-sized enterprises (SMEs) and grassroots entrepreneurs to thrive (Asadullah, 2021).

Moreover, advances in big data analytics and AI-driven business intelligence enable tourism entrepreneurs to enhance strategic decision-making (Siddiqui, 2025). Analytical tools provide insights into consumer trends, competitor activities, and operational efficiencies, allowing businesses to fine-tune marketing strategies, optimize pricing, and manage risks proactively (Anil Kumar & Ramesh Babu, 2025). This evidence-based approach supports sustainable growth and increases resilience amid external shocks such as pandemics or geopolitical fluctuations (Onyekwena & Edafe, 2024).

The growing adoption of IoT and smart technologies is further revolutionizing tourism operations and service delivery (Astanakulov et al., 2025). Smart sensors, wearable devices, and mobile applications collect real-time data on visitor flows, environmental conditions, and resource utilization, enabling entrepreneurs to optimize asset management, reduce waste, and enhance user experiences (Sankar & Ilangovan, 2025). These intelligent systems contribute to sustainable tourism practices aligning with global agendas for responsible resource use and environmental stewardship (Patrichi, 2024).

Blockchain technology also offers disruptive potential for tourism by increasing transparency, security, and trust in transactions and supply chains (Rana et al., 2022). For entrepreneurs, blockchain applications include secure payments, verified reviews, and decentralized loyalty programs, which build stronger relationships with customers and partners while reducing fraud and inefficiencies (Nawaz, 2024).

Despite its transformative potential, digital innovation presents certain challenges for tourism entrepreneurs. These include substantial capital investment requirements, digital skills gaps, cybersecurity risks, and regulatory uncertainties (Williams et al., 2021). Furthermore, technology adoption varies widely across regions and business sizes, leading to potential disparities in access to innovation benefits (Trouvain, 2024).

Nevertheless, digital innovation remains a critical catalyst for reimagining tourism business models, enabling entrepreneurs to craft more flexible, customer-centric, and sustainable enterprises (Santarsiero et al., 2024). By leveraging technologies such as AI, big data, IoT, and blockchain, tourism businesses can achieve new levels of efficiency, differentiation, and resilience (Rane et al., 2023). This evolving landscape offers fertile ground for the application of emergent quantum AI approaches as explored in this research, which promise to further amplify entrepreneurial capabilities in the digital era (How & Cheah, 2023).

## **2.5. Challenges and Opportunities in Implementing Quantum AI in Tourism**

The integration of quantum artificial intelligence (Quantum AI) into tourism entrepreneurship presents both significant opportunities and notable challenges that influence its adoption and impact on the industry (Kumar et al., 2025). While Quantum AI holds transformative potential to enhance decision-making, operational efficiency, and innovation, its widespread implementation is hindered by several technical, organizational, and socio-economic barriers (Marmon, 2025). Key technical challenges include hardware limitations, high computational costs, and the necessity for interdisciplinary expertise (Ahmadi, 2023). Alongside these, social and organizational factors such as resistance to technology adoption, gaps in digital infrastructure, and ethical considerations must be addressed to facilitate successful integration (Díaz-Arancibia et al., 2024). Despite these obstacles, the promising opportunities offered by Quantum AI—ranging from enhanced market responsiveness

and improved service personalization to advanced crisis management—highlight its crucial role in shaping the future trajectory of tourism entrepreneurship (How & Cheah, 2023).

One of the foremost challenges is the technical maturity and accessibility of quantum computing hardware. Quantum computers remain in an early developmental phase, frequently limited by qubit coherence times, error rates, and hardware scalability (De Leon et al., 2021). These limitations constrain the size and complexity of problems that can currently be addressed using quantum AI (Kusyk et al., 2021). For tourism entrepreneurs, many of whom operate with limited resources, access to sophisticated quantum computing infrastructure and expertise poses a significant hurdle (Kumar et al., 2025). Cloud-based quantum computing services partly alleviate this issue but come with cost and latency considerations, affecting real-time application in dynamic tourism environments (Padmanaban, 2024).

Another challenge lies in the complexity of domain-specific quantum algorithms suited to tourism applications (Marengo & Santamato, 2025). Developing and optimizing algorithms that effectively model multifactorial tourism ecosystems—incorporating tourist behaviors, environmental variables, and economic dynamics—is a highly specialized task requiring interdisciplinary collaboration among quantum physicists, data scientists, and tourism experts (Alsahafi et al., 2025). The relative novelty of this research area limits the availability of tested models and best practices, necessitating ongoing innovation and experimentation.

Data privacy and ethical concerns also represent critical considerations in deploying quantum AI in tourism (Boretti, 2024). Enhanced data processing capabilities raise questions about the responsible collection, storage, and usage of sensitive traveler data, necessitating compliance with regional and international data protection regulations (Herath et al., 2024). Tourism entrepreneurs must balance leveraging detailed personal and behavioral insights with respecting privacy and building consumer trust, an area where transparent AI governance frameworks remain nascent (Koo et al., 2025).

On the positive side, Quantum AI offers unparalleled opportunities for enhancing tourism entrepreneurship by enabling adaptive, data-driven decision-making at scales and speeds unattainable by classical systems (Sultana, 2024). Its capacity to simultaneously analyze multiple intertwined variables supports personalized travel experiences, dynamic resource allocation, and predictive crisis management, all key to entrepreneurial agility and sustained competitiveness (Junfeng & Butkouskaya, 2025). By accelerating innovation cycles, quantum AI can empower entrepreneurs to pioneer new business models that leverage real-time intelligence for market differentiation and operational excellence (Emma, 2022).

Furthermore, quantum AI's ability to efficiently solve complex optimization problems promises transformative enhancements in supply chain logistics, destination management, and sustainable resource use (Whig et al., 2024). This supports not only business profitability but also the broader goals of social inclusion and environmental stewardship, aligning with emerging global tourism priorities and the mission of entrepreneurial research platforms such as the Journal of Entrepreneurial Researchers (Nandhini ET AL., 2025).

Organizational and institutional readiness is another vital aspect shaping the adoption of quantum AI (Joy & Oladele, 2025). Education and skill development initiatives are required to bridge knowledge gaps among tourism professionals, entrepreneurs, and researchers, facilitating the translation of quantum AI innovations into actionable industry solutions (Kaal, 2024). Policy support and investment in digital infrastructure also play crucial roles in creating enabling environments for technology diffusion, especially in underserved regions or SMEs typically facing higher barriers (Akpe et al., 2023).

### *2.5.1. Governance and Responsible Innovation in Quantum AI for Tourism*

The use of quantum AI in tourism brings up significant ethical and privacy questions that need careful attention (Luís-Ferreira & Loureiro-Rodrigues, 2025). These systems handle vast amounts of sensitive traveler information, which raises concerns about how this data is collected, stored, and used (Bist, 2025). It's crucial to comply with data protection laws like GDPR, but the unique nature of quantum computing also means new challenges might



arise when it comes to keeping data safe and private (Bruno & Spano, 2021). On top of that, quantum AI's complexity can make its decision processes hard to understand (Raparathi et al., 2021), so it's important to develop ways to make these systems more transparent and explainable, helping build trust with customers and satisfy regulatory requirements (Balasubramaniam et al., 2023).

There are also broader social issues tied to adopting quantum AI in the tourism industry. Right now, access to quantum technology is limited, which could increase inequalities between larger, resource-rich companies and smaller players, or between different countries (Reddy et al., 2025). Since guidelines for responsibly managing quantum AI are still developing, there's a real need for collaboration among industry experts, policymakers, and researchers to create fair and accountable standards (Kop et al., 2023). Besides, quantum AI could change the way people work in tourism, influence how businesses interact with customers, and even affect the preservation of cultural heritage (Nuraeni et al., 2025). To make sure these changes benefit everyone, we need thoughtful policies and ongoing evaluation of the technology's social impact. Responsible development means focusing on privacy, fairness, and wider accessibility to ensure that quantum AI helps the tourism sector grow sustainably and ethically (Khan et al., 2024).

While the implementation of quantum AI in tourism entrepreneurship is challenged by technological, ethical, and capacity-building factors, its potential to revolutionize decision-making, innovation, and sustainability in the sector is immense (Palakurti, 2024). Navigating these challenges through collaborative research, strategic investments, and regulatory frameworks will be pivotal in harnessing quantum AI's promise for fostering resilient, innovative, and socially responsible tourism businesses.

### **3. Research Methodology**

This study investigates the complex and rapidly evolving environment of the tourism sector, where multifaceted and interdependent variables continuously influence entrepreneurial decision-making and the development of innovative business models. Recognizing that traditional analytical and computational methods have limited capacity to fully capture these nonlinear, dynamic interactions, the research employs an advanced methodological framework grounded in quantum artificial intelligence (Quantum AI). This approach allows for the simultaneous processing of diverse, interconnected factors, thus offering a sophisticated tool to simulate the complexity and uncertainty (Marengo & Santamato, 2025) inherent to tourism entrepreneurship and management (Williams et al., 2021).

The model was developed through a strong interdisciplinary collaboration that brought together experts from quantum computing and artificial intelligence with specialists in tourism management and entrepreneurship. The quantum computing team was instrumental in designing the algorithms, selecting appropriate quantum gates, and overseeing the simulation's logical and technical accuracy, ensuring that the quantum circuits operate according to theoretical principles. Meanwhile, tourism and entrepreneurship consultants provided guidance on the practical relevance of the variables included in the model, validated assumptions against industry realities, and helped integrate decision-making criteria that reflect real-world challenges faced by tourism entrepreneurs.

A crucial step in this research was the identification and definition of key variables and parameters that influence tourism business dynamics. Building on extensive literature reviews and specialist consultations, the model incorporates important independent factors such as environmental entropy, tourist preferences, destination capacities, social media influence, and economic indicators. These variables are critical because they represent the multidimensional environment in which tourism entrepreneurs operate. Their selection reflects an understanding of how external and internal system components interact to shape business outcomes, particularly in contexts demanding adaptability and innovation.

The core of the methodology lies in the construction of a 12-qubit quantum circuit simulation. This quantum model exploits fundamental quantum mechanics phenomena—such as superposition and entanglement—to simultaneously explore multiple possible system states and interactions. By encoding system variables within these quantum states, the model is capable of evaluating complex, multi-layered scenarios that reflect the

volatile and dynamic nature of tourism ecosystems. This advantage is particularly relevant for modeling scenarios that require real-time adaptation and personalized decision-making, as it allows the system to effectively manage uncertainty and complexity without the oversimplifications imposed by classical computing methods.

Simulation outputs generated by the quantum model were subjected to rigorous evaluation through engagement with a community of experts representing both the technological and tourism sectors. These experts reviewed the model's scenario analyses, including adaptive travel planning, service personalization, crowding mitigation, and crisis resilience strategies. Their feedback was essential for validating the conceptual soundness of the model, assessing its potential operational value, and suggesting refinements to improve the model's applicability and robustness. This iterative expert engagement reflects a participatory approach to model development, ensuring that the research remains grounded in both theoretical innovation and practical utility.

While this inquiry remains primarily exploratory and conceptual, it deliberately focuses on variables with high managerial relevance, such as the alignment of tourist preferences to services, optimization of space usage to reduce congestion, and the efficient deployment of infrastructure like accommodations and transport. By optimizing these dependent variables within the quantum simulation, the model demonstrates how Quantum AI can serve as a powerful decision-support tool that entrepreneurs can leverage to navigate uncertainty, tailor offerings, and enhance operational efficiency.

The limitation of this phase lies in the absence of real-world input data. Instead, synthetic and theoretical data representations were used to test and showcase the model's capacity to simulate intricate tourism dynamics. However, this sets a strong foundation for subsequent empirical studies, where actual traveler behavior data, environmental metrics, and business performance indicators will be integrated to calibrate and validate the model in practical settings. Such applied research will enable extraction of actionable insights and support evidence-based decision-making for tourism entrepreneurs facing diverse market conditions.

Importantly, the study situates Quantum AI as an innovative leap beyond current digital technologies, aligning with trends in entrepreneurship that emphasize agility, sustainability, and customer-centricity. By bridging disciplines and embracing computational complexity, it opens new horizons for creating intelligent tourism business models that are resilient, adaptive, and environmentally conscious.

This methodology represents a novel synthesis of quantum computational theory, AI, and entrepreneurship practice, advancing the development of intelligent, adaptive decision-making frameworks tailored for the inherently complex tourism industry. It lays the groundwork for future empirical validation and extension into other service sectors facing similar dynamic and uncertainty-driven challenges.

### **3.1. Reinterpreting Quantum Concepts for Tourism Entrepreneurship and Innovation**

This section aims to conceptually and practically clarify the foundational components of the quantum AI decision-support model, tailored specifically for tourism entrepreneurship and innovative business model development. Unlike traditional linear and unidimensional analytics, the model employs simultaneous and nonlinear data processing, reflecting the dynamic, multifactorial, and unpredictable nature of modern tourism markets (Stylos et al., 2021). By harnessing quantum computational principles, it integrates diverse variables—including tourist preferences, real-time environmental data, economic conditions, and operational constraints—into a cohesive decision-making framework (Arumugam et al., 2025). This enables entrepreneurs and managers to adopt adaptive, multi-layered strategies capable of navigating uncertainty, market volatility, and rapid changes (Yoon et al. 2025).

At the core of the model are three distinctive quantum computational structures, each contributing a unique function to the decision-making logic:

- **Analytical Gates (e.g., Hadamard):** These quantum gates enable the simulation of multiple potential future scenarios simultaneously (Alexeev et al., 2024). In the context of tourism entrepreneurship, this means the model can concurrently evaluate the effects of shifting economic trends, social behaviors,



and environmental factors on business opportunities and customer demand. This capability equips entrepreneurs with advanced decision-support tools to parallelize scenario analyses and strategically prepare for uncertain futures (Al-Shukri, 2024).

- **Interactivity Gates (e.g., CNOT):** These gates model causal and conditional relationships between variables, quantifying how variations in one factor, such as destination safety or regulatory changes, impact related tourist behaviors and entrepreneurial outcomes (Bataille, 2022). This dynamic mapping helps identify cascading effects across market dimensions, guiding entrepreneurs to anticipate and respond effectively to policy shifts, climate impacts, or reputation changes (Terchila, 2025).
- **Sensitivity Modulators (e.g., RX, RY, RZ Rotations):** These elements calibrate the influence of each variable on the model's outputs, allowing dynamic weighting of factors such as pricing, personalized services, or geographical market preferences (Chen et al., 2025). Such tunable sensitivity underpins the design of flexible recommendation systems and customized tourism offerings, enhancing competitive differentiation and customer engagement in diverse market segments (More & Pothula, 2025).

Beyond its computational strength, this quantum AI model represents a novel systematic approach to addressing the intricate and fast-evolving challenges faced by tourism entrepreneurs. By enabling real-time, multi-scenario analysis and adaptive decision-making under complex uncertainty, it greatly enhances entrepreneurial resilience, optimizes resource allocation, and facilitates innovative service creation that aligns with shifting consumer expectations and sustainability goals.

### **3.2. Using Quantum Algorithms for Entrepreneurial Problem Solving**

In this research, quantum circuits form the computational backbone for capturing and analyzing complex interplays among diverse business variables crucial to tourism entrepreneurship. Hadamard gates are employed to generate uniform distributions over possible system states, effectively exploring diverse scenario probabilities simultaneously (Jones et al., 2023). CNOT gates model dependencies and interactions among critical entrepreneurial factors, such as customer behavior influence by marketing strategies or destination safety (Zakablukov, 2021).

A key feature of this model is the calculation of von Neumann entropy, which measures the system's uncertainty and complexity, offering deep insights into the stability and predictability of entrepreneurial ecosystems (Kim et al., 2021). This metric guides the optimization of decision strategies to maximize adaptability and overall business performance (Hou et al., 2024).

Additionally, notable quantum algorithms are integrated into the framework. Grover's algorithm is utilized to optimize search operations within large, multidimensional tourism datasets, facilitating efficient extraction of valuable insights such as emerging trends or consumer segments (Hema & Arowolo, 2023). Meanwhile, Shor's algorithm, although traditionally applied in cryptography, offers potential for analyzing complex financial and operational patterns within tourism enterprises, supporting risk assessment and strategic planning (Mohammed, 2024).

Together, these quantum computational tools provide a robust, comprehensive platform for modeling highly complex tourism entrepreneurship data and generating optimal, agile solutions (Khan et al., 2024). This quantum AI-driven problem-solving approach transforms how entrepreneurs can manage uncertainty, innovate business models, and sustain competitive advantage in increasingly complex and unpredictable tourism markets (How & Cheah, 2024).

#### **3.2.1 Tested Scenarios**

To explore the complexities of tourism entrepreneurship and dynamic market responses, a quantum modeling framework was implemented to simulate and comparatively analyze real business environments. This framework integrates quantum computational structures with expert-driven analysis based on complex network theory, enabling a thorough examination of influential interactions and interdependencies central to entrepreneurial decision-making and innovation within tourism.



### 3.2.2 Implementation

The quantum AI model was implemented using a 12-qubit circuit designed to simulate the intricate interactions among diverse variables critical to tourism entrepreneurship and business innovation. This quantum simulation encodes key factors within the quantum states, leveraging superposition to process multiple possible scenarios simultaneously, while entanglement modeled through CNOT gates captures the conditional relationships and cascading impacts among variables. This setup allows for a comprehensive representation of the multifaceted and dynamic tourism ecosystem, enabling the examination of how shifts in one element propagate through others and influence overall entrepreneurial outcomes. By using quantum gates and circuits, the model simulates complex, real-time decision-making environments where uncertainty, nonlinearity, and interdependence prevail.

### 3.2.3. Six Key Variables for Simulation in the 12-Qubit Circuit

#### (1) Tourist Preferences

- Individual-specific data including interests, travel styles, emotional needs, and experiential desires.
- Example: Choices between cultural heritage visits and leisure-focused itineraries affect personalized service design.

#### (2) Real-Time Environmental Conditions

- Dynamic factors such as weather changes, air pollution levels, transportation disruptions, and natural disasters.
- Essential for adaptive route planning and responsive destination recommendations.

#### (3) Economic Factors

- Variables including exchange rates, pricing strategies, and overall travel costs.
- Directly influence tourists' purchasing power and destination selection.

#### (4) Health & Safety Indicators

- Factors encompassing epidemic outbreaks, political stability, health crises, and destination security.
- Highly influential in travelers' risk assessments, especially post-pandemic.

#### (5) Social Media Trends & Sentiments

- Real-time analysis of user-generated content, trending destinations, and peer recommendations.
- A key driver of rapidly evolving tourist behaviors and demand patterns.

#### (6) Resource Availability & Destination Capacity

- Includes accommodation capacity, transport accessibility, and crowding levels at sites.
- Critical to visitor experience quality and sustainable tourism management.

Hadamard gates were employed to generate superposition states representing all potential variable combinations concurrently. CNOT gates facilitated the modeling of entangled interactions and causal dependencies between variables. This quantum-inspired modeling framework provides a system-wide perspective on how variations in key factors influence each other and the entrepreneurial environment as a whole. Von Neumann entropy was used as a quantitative metric to assess system uncertainty and complexity, offering insights into the stability and responsiveness of tourism entrepreneurship ecosystems under simulated scenarios. This entropy measure helps gauge the impact of variable interplay on decision-making robustness and adaptive capacity.



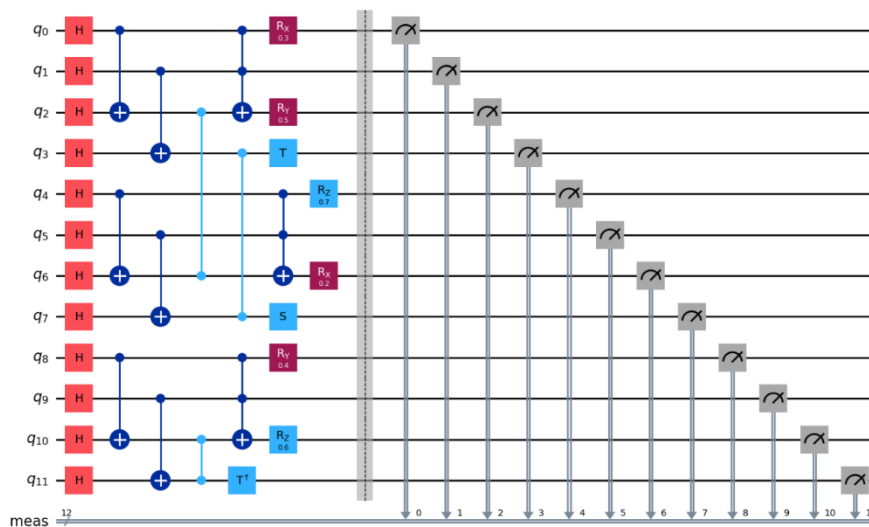
Figure 1: Output circuit from the implemented state.

```
from qiskit import QuantumCircuit, Aer, execute
from qiskit.quantum_info import DensityMatrix, entropy, Statevector
from qiskit.visualization import plot_histogram, plot_state_city,
plot_bloch_multivector
import matplotlib.pyplot as plt
num_qubits = 12
qc = QuantumCircuit(num_qubits)
for i in range(num_qubits):
    qc.h(i)
qc.cx(0, 2)
qc.cx(4, 6)
qc.cx(8, 10)
qc.save_statevector()
backend = Aer.get_backend('statevector_simulator')
job = execute(qc, backend)
result = job.result()
state = result.get_statevector()
rho = DensityMatrix(state)
quantum_entropy = entropy(rho, base=2)
print("Quantum Entropy:", quantum_entropy)

plot_histogram(result.get_counts(qc))
plt.title('Histogram of Measurement Outcomes')
plt.show()

plot_state_city(rho, title="Density Matrix")
plt.show()
state_vec = Statevector.from_instruction(qc)
plot_bloch_multivector(state_vec)
plt.show()
```

**Diagram 1:** 12-qubit quantum circuit with multiple interactions, entanglement, and phase shifts.



This quantum circuit consists of 12 qubits initially prepared in a superposition state using Hadamard (H) gates, enabling simultaneous consideration of multiple scenarios. Entanglements between qubits are then created through CNOT gates, capturing interdependencies and complex interactions among variables. Phase gates (T, T<sup>†</sup>, S, Z) and rotational gates (Rx, Ry, Rz) are applied to introduce phase shifts and control the evolution of the quantum state over time, simulating dynamic changes in the system. The circuit concludes with measurements of all qubits, producing outputs that reflect the combined effects of all variables and their interactions.

This circuit architecture models a sophisticated quantum system well-suited for analyzing nonlinear relationships, uncertainties, and interrelated effects across multiple tourism entrepreneurship variables. It supports the simulation of diverse scenario outcomes, providing a powerful computational framework for adaptive decision-making in complex, volatile market environments. The specific scenarios generated by the interplay of these quantum gates will be detailed in the following section.

### 3.2.4 Quantum State Encoding Strategy

Each of the six key tourism variables introduced in this study is encoded into quantum states to enable effective simulation and analysis within the 12-qubit quantum circuit. The encoding approach balances the nature of the data including binary, categorical, and continuous variables and the constraints of quantum computation.

- **Qubit Assignment**
  - Each variable or pair of related variables is mapped to specific qubit(s). For example, tourist preferences are represented using two qubits to capture multiple preference categories and intensities, while real-time environmental conditions are assigned two qubits reflecting continuous metrics such as weather variables.
- **Data Preprocessing and Normalization**
  - Before encoding, continuous data such as environmental factors and economic variables are normalized to a range to facilitate quantum angle encoding. Categorical variables like destination safety levels are transformed to binary or one-hot encoded formats to be compatible with basis state encoding.
- **Encoding Techniques**
  - Three primary quantum encoding methods are applied depending on variable characteristics:
    - *Basis encoding* translates binary data into computational qubit basis states  $|0\rangle$  and  $|1\rangle$ .
    - *Angle encoding* uses qubit rotation gates (e.g., RX, RY) to encode normalized continuous variables as rotation angles on single qubits.



- *Amplitude encoding* is explored for complex variables, embedding multidimensional continuous data into amplitude probabilities of superposition states but currently limited by circuit complexity.
- **Reflecting Uncertainty and Correlations**
  - The model incorporates uncertainty inherent in tourism dynamics through initial superposition states created by Hadamard gates, allowing a probabilistic representation of variable states. Correlations between variables such as between social media trends and tourist behavior are modeled through entanglement operations (e.g., CNOT gates), enabling the circuit to capture interactive effects that classical models may overlook.

This structured encoding process ensures that the quantum circuit effectively represents the multifaceted tourism ecosystem, allowing for dynamic and concurrent analysis of interdependent variables critical to entrepreneurial decision-making.

### 3.3. Managerial Reinterpretation of Quantum Circuit Diagrams

Though the quantum circuit proposed in this study may appear primarily as a technical assembly of logical gates and quantum computational elements, it can be conceptually reframed as a sophisticated decision-support system tailored for tourism entrepreneurship and innovation. This architecture enables the simultaneous analysis of multiple interrelated factors shaping dynamic business environments and personalized tourist experiences.

The circuit's 12 qubits represent six pairs of interdependent variables, each pair modeling systemic relationships between critical entrepreneurial and operational factors—such as the interplay between traveler preferences and environmental or infrastructural constraints. This pairing reflects the complex, intertwined nature of decision variables in tourism business models.

From a managerial perspective, Hadamard gates (H) enable the parallel simulation of probabilistic scenarios, offering entrepreneurs and managers a powerful tool analogous to prospective scenario planning under uncertainty. This capability supports evaluating multiple potential market outcomes simultaneously to inform strategic decisions.

CNOT gates function as causal connectors between variables, mirroring how shifts in one domain—a change in currency exchange rates or a political event affecting destination safety—translate into behavioral changes among tourists. In entrepreneurial terms, they allow the modeling of ripple effects throughout business systems, guiding adaptive responses.

The fuzzy gates (S, T, Z) and rotational gates (Rx, Ry, Rz) serve to modulate the influence and sensitivity of individual factors on the model's outputs. Strategically, these gates enable prioritization and dynamic weighting—allowing entrepreneurs to adjust how factors such as economic conditions, health and safety indices, or service quality affect travel demand and operational decisions.

The final measurement process synthesizes the modeled interactions into concrete outputs, producing actionable insights. These results can inform the design of personalized travel offerings, optimization of tourist flows across destinations, and the development of innovative business strategies that respond flexibly to real-time market signals.

Overall, the quantum circuit diagram transcends its technical complexity to embody a flexible, adaptive decision-making framework. It provides tourism entrepreneurs with a multi-layered, interactive tool that enhances understanding and management of volatile and multifactorial market conditions, supporting innovation and resilience in an ever-changing global tourism landscape.



**Table 1:** Scenarios derived from the quantum circuit.

Scenario	Scenario Description	Relation to Research Title	Interpretation Based on Quantum Circuit
Adaptive travel route suggestions based on real-time weather conditions	Adjusting travel routes instantly based on sudden environmental changes and tourist preferences.	Demonstrates dynamic decision-making under uncertainty, aligned with creating dynamic travel experiences in the title. AI system based on quantum intelligence responds to environmental changes with customized solutions.	- Hadamard (H) gates: Create superposition states for various weather scenarios. - CNOT gates: Create entanglement between environmental conditions and tourist preferences. - RX rotations (q0 and q6): Weighting the impact of environmental conditions. - Adaptive and instantaneous output after circuit measurement.
Recommendations for less crowded and sustainable destinations in response to increased demand on social networks	Guiding tourists to less crowded destinations to prevent overcrowding and enhance travel experience quality, by analyzing social network trends.	Supports customized and sustainable experiences. Quantum AI, with its rapid data analysis, aids in adaptive demand management and provides optimal decisions.	- RY and RZ rotations on q2, q4, and q10: Modeling the intensity of social media trends and destination resource capacity. - T and T <sup>†</sup> gates: Simultaneous analysis of different scenarios for destination selection. - CNOTs: Link social trends with actual destination capacities. - Proposing optimal destinations after circuit measurement.
Optimization of the tourism service supply chain (accommodation and transportation) during crises	Intelligent and optimal resource allocation management in crisis situations such as pandemics or economic crises.	Represents AI-based decision-making in uncertain conditions. Leads to continued customized and dynamic services despite instability.	- Hadamard (H) gates: Display superposition for all possible states of resources and demand. - RX/RY rotations (q0, q2, q6, q8): Modeling crisis intensities and their impact on resources. - S and T gates: Analyzing delayed responses during crises. - Adaptive decision-making for optimal resource allocation.
Predicting tourist behaviors and customizing travel experiences based on multi-source data	Accurately predicting tourist behaviors by analyzing real-time data from various sources and providing customized recommendations.	Directly related to creating customized travel experiences. The system, by analyzing data and current conditions, offers services tailored to each tourist's unique profile.	- Hadamard gates and RX, RY, RZ rotations: Modeling tourist behaviors and external conditions. - CNOTs (q0 to q11): Entangling behavioral and economic variables with individual preferences. - T <sup>†</sup> on q11: Analyzing unexpected tourist



Scenario	Scenario Description	Relation to Research Title	Interpretation Based on Quantum Circuit
Crisis management and enhancing the resilience of tourist destinations	Assisting tourist destinations to respond quickly and effectively to environmental and health crises and maintain service quality.	Shows smart decision-making under quantum uncertainty and helps provide sustainable and customized travel experiences even in unpredictable and crisis situations.	<p>reactions. - Offering customized suggestions after measurement.</p> <p>- Minor RX/Ry rotations: Modeling sensitive yet impactful changes in health and the environment. - CNOTs: Displaying the interaction between health indicators, resource capacities, and environmental conditions. - S gate on q7: Analyzing the system's delayed response during crises. - Developing rapid response and resilience strategies after measurement.</p>

The table demonstrates that the proposed scenarios clearly align with the three main axes of the research title:

- **Decision-Making Under Uncertainty (Quantum Uncertainty):** Applying quantum mechanics principles to analyze and adaptively respond to complex, variable data inherent in entrepreneurial tourism dynamics.
- **Dynamic Travel Experiences:** Enabling real-time adaptation to environmental shifts and tourist behavior changes, supporting agile business responses.
- **Personalized Travel Experiences:** Facilitating the creation of customized services and offerings tailored to individual tourist profiles and evolving contextual factors, driving business model innovation.

### 3.4. Managerial Reinterpretation of Scenario Tables

The scenario table generated from quantum simulations in this study functions as an interactive decision-support framework, seamlessly linking advanced data-driven analysis with practical, actionable recommendations for tourism entrepreneurs and managers. Each scenario is carefully structured to capture the complexity of dynamic market conditions and translate these insights into strategic entrepreneurial initiatives.

- **Low-Pressure Destination Guidance Scenario:** By applying Ry and CNOT gates on qubits representing visitor density and demand trends, the model identifies patterns of tourist concentration and suggests optimal distribution strategies. These insights support targeted marketing efforts and efficient resource deployment to underutilized destinations, enhancing both visitor satisfaction and sustainability.
- **Dynamic Tourism Supply Chain Management Scenario:** Utilizing Hadamard and Rx gates, the model evaluates the availability and status of key tourism resources—including accommodation, transport, and ancillary services—while assessing associated risk factors. This enables real-time adaptive resource allocation, critical for maintaining operational agility and resilience in fluctuating market conditions.
- **Intelligent Travel Experience Customization Scenario:** By combining behavioral data (such as booking histories and online interactions) with economic variables through quantum entanglement (CNOT + Rz gates), the system generates personalized travel packages that evolve dynamically with individual tourist preferences and contextual changes, fostering competitive differentiation and enhanced customer loyalty.



Far beyond a technical output explanation, this table represents a strategic platform for innovative policymaking and entrepreneurial decision-making. It exemplifies how quantum AI models can be translated into flexible, intelligent business and policy strategies that meet the complexity and evolving demands of contemporary tourism markets.

#### 4. Conclusion

This study confronts the growing complexity and uncertainty characterizing today's tourism industry—an environment shaped by rapid economic, environmental, technological, and social transformations. Rising tourist demands for personalized and adaptive experiences compound these challenges, emphasizing the need to advance beyond traditional management and analytical frameworks. In response, this research developed an innovative, quantum AI-driven decision-making model designed to support entrepreneurship and business innovation in tourism by harnessing the power of quantum mechanics and artificial intelligence.

A thorough review of the relevant literature highlighted how advances in AI techniques—particularly machine learning, reinforcement learning, and deep neural networks—equip practitioners with robust tools for analyzing large-scale data and tailoring dynamic travel experiences. Complementing this, foundational principles of quantum mechanics, including uncertainty, superposition, entanglement, and quantum entropy, offer a powerful theoretical basis to model and manage the complex, nonlinear, and interdependent variables inherent in tourism ecosystems.

The core of the proposed model consists of a 12-qubit quantum circuit simulating six critical, interconnected variables affecting tourism entrepreneurship: tourist preferences, real-time environmental conditions, economic factors, health and safety indicators, social media trends and sentiments, and resource capacity at destinations. This integrated modeling approach enables real-time analysis of nonlinear interactions, empowering highly adaptive, optimized decision-making under conditions of uncertainty and market volatility.

Results from simulated scenarios validate the model's efficacy in shaping entrepreneurial strategies that foster dynamic and personalized travel experiences. Key scenarios include adaptive travel route recommendations responding to weather changes, guiding tourists toward less congested destinations informed by social media insights, optimizing supply chains during crises, predicting tourist behavior for personalized service offerings, and enhancing destination resilience in the face of environmental and health emergencies.

By embedding quantum uncertainty principles into AI-driven decision-making, the model elevates the capacity to navigate and manage the turbulent, multifactorial landscape of global tourism. Beyond personalization and enhanced satisfaction, it contributes to system sustainability and entrepreneurial resilience, demonstrating wide applicability for service industries characterized by complexity and rapid change.

Looking ahead, future research should prioritize the development of scalable quantum computing infrastructure suitable for commercial and real-world deployment, strengthen data security and privacy frameworks within quantum AI systems, and encourage interdisciplinary partnerships to facilitate practical application in live tourism environments. Additionally, exploring quantum reinforcement learning offers promising avenues for designing the next generation of adaptive, context-aware decision algorithms.

This quantum computing-based decision-support model moves beyond theoretical abstraction to present a practical tool addressing the layered challenges of tourism entrepreneurship. Leveraging quantum parallelism, state concurrency, and uncertainty modeling, it fosters dynamic reconfiguration of decision environments across three pivotal domains: managing fluctuating demand, designing interactive and personalized services, and enabling rapid crisis response. Specifically, it integrates operational capacities, climatic factors, and digital behavior analytics to predict tourist flows and optimize infrastructure use, empowering entrepreneurs to redirect demand dynamically toward underutilized destinations during peak periods.

In service design, the model enables the creation of intelligent, real-time personalized travel packages by entwining emergent behavioral data with economic variables. In crisis management—such as environmental



disasters or pandemics—it offers a resilient scenario-building platform for agile reallocation of resources and adaptive route planning.

Collectively, these findings illustrate how the fusion of quantum computational frameworks with entrepreneurial decision-making logic opens transformative opportunities for innovation in tourism strategy and policy. This paradigm shift transcends simulation, offering actionable and generalizable evidence to fuel resilient, adaptive, and sustainable tourism entrepreneurship in an increasingly uncertain world.

### **5. Research Limitations and Future Development Pathways**

This study, positioned as a theoretical and exploratory investigation, centers on designing an innovative quantum AI-based framework to model complex, adaptive, and multidimensional decision-making processes within tourism entrepreneurship and business innovation. The framework was primarily developed through quantum circuit simulations and conceptual analyses, without direct application to empirical real-world data or live operational environments. Its focus has been on establishing the theoretical foundations and demonstrating the framework's ability to capture and represent the intertwined effects of behavioral, environmental, economic, and structural variables at various scales—from individual tourist preferences to broader market and policy dynamics.

A key limitation of this work is the lack of empirical testing and validation using actual tourism data, which constrains the assessment of its practical effectiveness in real entrepreneurial settings. To enhance the model's robustness and utility, future research must bridge this gap by integrating the quantum AI framework with operational tourism systems and real-world datasets. This could involve implementing the model within the recommendation engines of tourism companies to personalize travel experiences, or simulating crisis management scenarios for destinations using historical and live data streams to validate adaptive decision-making capabilities.

Further development should prioritize active collaboration with industry stakeholders, including entrepreneurs, destination managers, and policymakers, to co-design participatory field studies that evaluate the model's practical applicability and usability in diverse tourism contexts. Such efforts will enable comprehensive testing of the model's adaptability, identification of operational strengths and limitations, and refinement of implementation tools tailored for entrepreneurial decision support.

Additionally, advancing the computational infrastructure, particularly quantum hardware accessibility and scalability and addressing data security and ethical considerations in quantum AI applications will be critical for transitioning the framework from concept to commercial viability. While the proposed quantum AI framework offers promising theoretical advancements for tourism entrepreneurship, its practical implementation faces significant challenges imposed by current quantum hardware NISQ devices. These devices, widely regarded as the first generation of usable quantum computers, have several inherent limitations that constrain the model's scalability and real-world effectiveness.

Key hardware constraints of current quantum technologies include limited qubit coherence times, meaning that qubits retain quantum information only briefly due to decoherence, which restricts the depth and complexity of quantum circuits that can be reliably executed. Additionally, quantum gate operations are prone to noise and inaccuracies, causing errors that reduce computational fidelity and necessitate the use of error mitigation techniques to ensure reliable outputs. Scalability also remains a significant challenge, as existing quantum processors have a limited number of qubits, which constrains the volume and dimensionality of data that can be encoded and processed simultaneously especially critical for tourism applications involving numerous variables and large datasets. Furthermore, the lack of efficient and scalable quantum memory (qRAM) impedes the rapid loading and retrieval of classical data into quantum registers, creating a bottleneck for data-intensive, practical applications.



To address these limitations, the research model can adopt several adaptation strategies. Hybrid quantum-classical methods combine quantum circuits for solving key subproblems with classical algorithms, thereby leveraging quantum advantages within current hardware constraints while relying on classical processing for data-intensive tasks. Circuit depth optimization involves designing shallower quantum circuits by selecting essential variables, applying approximation techniques, or decomposing problems, which helps reduce the risks of decoherence and error accumulation. Additionally, error mitigation techniques, such as zero-noise extrapolation and probabilistic error cancellation, improve output quality without the need for full quantum error correction. Finally, focused use of encodings by prioritizing variables most critical to decision-making and encoding them efficiently optimizes the use of limited qubit resources.

Despite these constraints, ongoing improvements in NISQ hardware and algorithm design hold promise for progressively expanding quantum AI's applicability in tourism entrepreneurship. A clear understanding of these limitations informs realistic expectations and guides the development of practical, near-term quantum-enhanced decision-support tools.

Ultimately, integrating the theoretical rigor of this quantum decision-making model with empirical validations and industry engagement can create a credible foundation for embedding quantum AI-driven innovation within tourism entrepreneurship, fostering smarter, more resilient, and sustainable business practices in the increasingly dynamic global tourism landscape.

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## Ethics, truth, and values in political economy research: Implications for entrepreneurship and innovation

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### Abstract

Science rests on an ethics of responsibility, which presupposes the autonomy of researchers and their freedom of choice, while holding them accountable for their decisions. Yet, social, moral, and other non-cognitive values inevitably shape scientific practice, not only in matters of research ethics but also in methodological choices and the very selection of problems to be investigated. This raises fundamental questions: if science is permeated by values, can it still be regarded as “neutral” and “autonomous”? This essay argues that values are not a contaminant to be eliminated but an epistemic infrastructure that constitutively shapes rigorous and socially relevant knowledge in political economy and entrepreneurship studies. Moreover, is science truly “impartial” in its cognitive evaluation of results, as a condition for valid knowledge? These questions frame the present reflection. The analysis suggests, in a broad sense, that ethics can be understood as the pursuit of truth, with all the particularities implied by the definition of both truth and values.

**Keywords:** Political Economy; Positive Change; Power; Science; Sociology.

### 1. Introduction

Ethics is historically situated: what one era deems acceptable another may condemn. This historicity shapes both social practices and scientific inquiry. As Max Weber argued in *Wissenschaft als Beruf*, science is never entirely divorced from values; even the demand for “value-neutrality” is a normative stance tied to cultural and historical conditions (Weber, 2004/1917). Likewise, Jürgen Habermas showed that knowledge is guided by human interests—technical, practical, or emancipatory—undermining the idea of a fully autonomous science (Habermas, 1971/1968).

In a period marked by rapid technological disruption (e.g., AI, biotech) and persistent global inequalities, the question of how values guide scientific and entrepreneurial action has renewed urgency. The legitimacy of innovation ecosystems increasingly depends on their ethical foundations. Recent scholarship indicates that philosophy remains central to understanding entrepreneurship as a value-driven practice, where ethical and epistemological commitments shape innovation and creativity (Leite, Audretsch, & Leite, 2024; de Almeida Leite, Audretsch, & Leite, 2025).

This exploration critically evaluates ethics within scientific research, emphasising Political Economy and its intersections with innovation and entrepreneurship. It adopts an exploratory and conceptual approach grounded in a critical literature review across philosophy, sociology of science, political economy, and entrepreneurship. Searches in Scopus, Web of Science, and Google Scholar (1968–2025) used keywords such as “ethics in science,” “values in political economy,” “entrepreneurship ethics,” and “responsible innovation” for peer-reviewed articles, books, and book chapters, excluding non-peer-reviewed sources (e.g., conference papers, grey literature) to ensure academic rigour. Inclusion criteria prioritised (i) works in English or Portuguese, reflecting the research team’s linguistic capabilities and the global dominance of English alongside the regional relevance of Portuguese in Lusophone contexts; (ii) disciplinary diversity across philosophy, sociology, political economy, and entrepreneurship; (iii) global relevance, incorporating perspectives from North America, Europe, and emerging

economies of economic and research significance (e.g., Brazil, India); and (iv) impact or seminal status (e.g., Weber, 2004/1917; Habermas, 1971/1968; Leite, Audretsch, & Leite, 2024; de Almeida Leite, Audretsch, & Leite, 2025). Approximately 40 sources were selected and synthesised through thematic analysis, coding sources to identify convergences and gaps across three streams: value-free ideals, value-laden perspectives, and socio-political critiques.

Moving beyond the neutrality–value dichotomy, we propose ethics as constitutive of knowledge production—a form of epistemic infrastructure that orients legitimate problems, methods, evidence, and outcomes in Political Economy and entrepreneurship. Classic managerial prompts—e.g., Blanchard and Peale’s (1988) questions about legality, justice, reciprocity, and public scrutiny (cf. Holjevac, 2008)—retain salience in scientific contexts, foregrounding ethics as a structuring axis of legitimacy within academia and society.

This essay offers three contributions: (1) it consolidates arguments that values are integral to scientific practice yet compatible with objectivity under conditions of critique and transparency; (2) it proposes a model of ethics as epistemic infrastructure with testable propositions for entrepreneurship; and (3) it links this model to responsible innovation to inform entrepreneurial ecosystem design. The remainder proceeds as follows: Section 2 reviews the three theoretical streams—value-free science, value-laden perspectives, and socio-political critiques—highlighting convergences and tensions. Section 3 develops the proposed model and its implications for entrepreneurship, formulating testable propositions. Section 4 synthesises the framework (Figure 1) and links it to responsible innovation. The conclusion summarises contributions, notes limitations, and outlines an agenda for empirical assessment of the epistemic-infrastructure model in entrepreneurial ecosystems.

## **2. Ethics and the Value-Laden Nature of Science**

The literature reveals three major perspectives on the relationship between science and values: (i) the ideal of value-free science (Weber, 1917/2004; Popper & Popper, 2002), (ii) critical accounts highlighting the inevitability of value-ladenness (Lacey, 2005, 1999a, 1998; Longino, 2002, 1990; Brown, 2021), and (iii) socio-political perspectives linking science to ideology and power (Marx & Engels, 2007; Galbraith, 1958; Neves, 2019).

Within this debate, the ideal of a value-free science presupposes that scientific inquiry should be conducted without the influence of subjective values. This notion can be traced back to Max Weber. In *Wissenschaft als Beruf*, Weber (1917) argued that scientific investigation ought to be guided exclusively by epistemological values such as focus, prediction, and empirical logic, all coherently linked to results. For Weber, the intrusion of other types of values—ethical, political, or religious—would compromise objectivity (Cupani, 2021).

Yet, once the presence of researchers throughout the scientific process is acknowledged, it becomes evident that an interaction between science and values is unavoidable. Values are inevitably embedded in research teams, shaping not only their approaches but also the ways in which results are interpreted by different audiences through their ideological lenses (Aymoré & Ferreira da Cunha, 2021; Dasgupta, 2009).

Hugh Lacey (2005) and Bunge (1999) raise similar concerns with respect to experimental research, its practical applications, and the very selection of problems deemed worthy of investigation. By contrast, Karl Popper placed emphasis on science as grounded in an ethics of responsibility: a relationship of freedom and commitment on the part of scientists towards their discipline. According to Popper and Popper (2002), this responsibility is exercised through the logical criterion of scientificity he proposed, as well as the methodological rules selected by scientists themselves. Such reflections were elaborated across several of his works, including *The Two Fundamental Problems of the Theory of Knowledge* (1930–1933), *The Logic of Scientific Discovery* (1934), *The Moral Responsibility of the Scientist* (1969), *Tolerance and Intellectual Responsibility* (1983), and *The Open Society and Its Enemies* (1974).

Recent scholarship reinforces this interpretation. De Assis Dias (2021), for instance, highlights how Popper’s conception of scientific responsibility entails not only methodological rigor but also a strong ethical commitment to society. In her view, Popper’s ethics is anchored in the idea that the scientist’s autonomy must be matched by



accountability, thereby anticipating contemporary debates on the social responsibilities of science and innovation

Within the specific field of Political Economy, the distinction between the two phases of economic production appears crucial to preserve scientificity. Chirat (2018) even considers it naïve to assume that Political Economy could ever provide a straightforward teaching of truth, since historians such as Galbraith have long recognised that both social and scientific arenas are governed by conflicts of interest and ideological struggles.

Galbraith (1958) and Chirat (2018) build on Marx and Engels's (2007) insight that dominant societal ideas often reflect the interests of the ruling class, shaping both economic thought and scientific inquiry. This suggests that political economy researchers must critically engage with ideological influences, acting as active disseminators of knowledge rather than passive conduits for prevailing narratives. Such a stance aligns with Neves's (2019) call for economists to reduce subjective biases through dialectical critique, ensuring scientific rigor without denying the role of values.

From this perspective, one might argue that economists should become active disseminators of their own ideas, rather than mere opinion makers at the service of the ruling class (Chirat, 2018).

Philip Kitcher (2001), however, raises a further question: what ought to be the goal of science in a democratic society? For some, the answer lies in the pursuit of truth; for others, it does not. In practice, truth and democracy may attempt to provide different and sometimes conflicting answers.

Truth may eventually be understood as correspondence to a mind-independent world. Yet science could not reasonably expect to uncover the entirety of such truth. Scientific inquiry must, by necessity, remain selective, concentrating on those aspects of nature that are judged to be most significant.

This, in turn, raises a further problem: how should such judgements be made? Kitcher's answer is that the pursuit of truth must be combined with respect for democracy. Research that we should deem significant is that which addresses the questions identified as most important through informed deliberation among those committed to the well-being of all. In fact, his book develops this perspective into an ideal of well-ordered science, linking it both to past efforts in science policy and to the recognition that the discovery of truth is not always identical with what society most needs or wants. Kitcher concludes with a chapter devoted to the responsibilities of scientists.

Helen Longino seeks to break the prevailing deadlock in the ongoing "science wars" between philosophers of science and sociologists of science—academic battles grounded in disagreement over the role of social forces in the construction of scientific knowledge. Many philosophers of science tend to minimise the role of social forces, insisting that scientific knowledge is best regarded as the outcome of cognitive processes. By contrast, sociologists argue that a range of non-cognitive factors influence what scientists learn, how they package it, and how readily it is accepted.

Underlying this disagreement is a common assumption: that social forces are primarily sources of bias and irrationality. Longino challenges this assumption, arguing instead that social interaction actually strengthens our ability to secure reliable and rational knowledge. This is a crucial insight, enabling her to develop a durable and innovative account of scientific knowledge that integrates the social and the cognitive.

In *Science as Social Knowledge*, Longino (1990) begins with a detailed discussion drawing on a wide range of contemporary thinkers who write on scientific knowledge, clarifying the philosophical issues at stake. She then critically examines the dichotomous understanding of the rational and the social that characterises both sides of the debate in science studies, and sets out the social account she deems necessary for an epistemology of science that encompasses the full spectrum of cognitive processes. Throughout, her account responds not only to the normative uses of the term "knowledge" but also to the social conditions under which scientific knowledge is produced.



Building on these ideas, Longino brings her account into dialogue with ongoing work in social epistemology and science studies, demonstrating how her critical social approach can help resolve a variety of persistent problems. Although the book is primarily epistemological in its concern with the sociality of inquiry, Longino also explores its implications for scientific pluralism. She thus advances a social account that preserves a meaningful concept of knowledge in the face of theoretical plurality and uncertainty.

Matthew Brown, for his part, aligns with authors such as Lacey, Longino, Kitcher, and Douglas. Indeed, he argues that extra-scientific values can enhance scientific practice, making it not only more socially responsible but also more intrinsically rigorous (Cupani, 2021).

This debate also resonates with studies in entrepreneurship and innovation, where social and ethical values condition how opportunities are recognised, how resources are allocated, and how scientific narratives legitimise organisational practices (cf. Audretsch, 2009; Shepherd, 2015; Zahra & Wright, 2016; Dacin, et al., 2011). Epistemology is therefore not neutral in relation to the economic–organisational field, but directly influences the creation and dissemination of applied knowledge.

Beyond highlighting value-ladenness in scientific practice, entrepreneurship research shows that the very sources of knowledge entrepreneurs rely upon—universities, incumbents, users, or public research—shape which opportunities become thinkable and legitimate, and with what ethical implications (Audretsch & Link, 2018). Likewise, the social role ascribed to entrepreneurship—whether oriented to rent-seeking, inclusion, or prosocial impact—depends on normative commitments embedded in policy and scholarly narratives (Zahra & Wright, 2016). These insights reinforce that epistemology is never neutral vis-à-vis the economic–organisational field; it configures what counts as salient evidence, credible action, and socially acceptable innovation.

In practice, Brown adopts a pragmatic stance fundamentally inspired by Dewey. He thus belongs to the current of normative pragmatism, in a double sense: in relation both to scientific practice and to value judgements.

In sum, the review of the literature reveals two enduring stereotypes. The first holds that science produces knowledge that is “true, certain, reliable, unequivocal, and decisive” (Brown), and that the activity generating it cannot be contingent. The second assumes that values are purely subjective—a matter of personal preference—and therefore necessarily constitute sources of distortion or bias in knowledge.

Thus, the debate has evolved from Weber's ideal of value-neutrality (i), through the recognition of inevitable value-ladenness (ii), to the critical analysis of science as an arena of ideological struggle (iii). This progression reveals that the central question is no longer whether values play a role, but which values should be justified and how.

As Neves (2019) observes, “The subjectivity and the different “visions” (ideologies) and “possible consciousnesses of economists—considered as “enemies” of scientificity (Pimenta)—are in this context inevitable and inexorably mark the selection and interpretation of “facts”, and, more generally, all scientific work.” Yet, the impossibility of denying subjectivity and values does not invalidate the possibility of objective knowledge. Such objectivity emerges from the scientific method itself, from the fact that theories are open to critique—a dialectical process of “reducing the subjectivities inherent to the various ‘possible consciousnesses’ that the social fabric shapes” (Neves, 2019, p. 206).

### **2.1. Synthesis and transition**

In short, neutrality is untenable, value-ladenness is inevitable, and socio-political critique is indispensable. What follows therefore shifts from *whether* values permeate inquiry to *how* explicit ethical infrastructures recalibrate what counts as salient evidence and legitimate outcomes in applied arenas. We develop this shift in entrepreneurship, where ethical commitments have material consequences for opportunity recognition, resource allocation, and distributional impact.

### **3. From Political Economy to Entrepreneurship: Ethical Dimensions of Knowledge Production**

Ethics today commands increasing attention and recognition, yet it is neither a recent concern nor one exclusive to contemporary societies. The great philosophers of classical antiquity consistently addressed ethics in relation to honesty, justice, and life in community, particularly in the domain of work.

The link between Political Economy and Entrepreneurship lies in their shared concern with the production and legitimation of knowledge. While Political Economy has long debated the role of ideology in economic knowledge, entrepreneurship studies show how value-laden narratives legitimize certain opportunities, resources, and actors over others (Audretsch & Link, 2018; Zahra & Wright, 2016). Thus, entrepreneurship can be viewed as the applied arena where the value-leadenness of economic knowledge becomes materially consequential. In other words, entrepreneurship and innovation, ethical commitments materialise in how knowledge sources are prioritised and valorised (e.g., scientific versus user-led knowledge) and in how entrepreneurial activity is framed as serving broader social purposes (Audretsch & Link, 2018; Zahra & Wright, 2016).

#### **3.1. Historical Foundations**

In the classical period, Aristotle (384–322 BCE) classified ethical problems under *practical philosophy*, insofar as this branch examined human action and the natural aspiration for fulfilment and happiness. For Aristotle, there was no universally valid rule defining happiness; rather, reason—strongly influenced by Socratic thought—enabled human will to guide actions towards useful and virtuous ends. Gradually, such axioms established patterns of behaviour tied to reason and responsibility. Aristotle distinguished two kinds of virtues: rational and moral–ethical (Holjevac, 2008).

Kant (1724–1804), by contrast, grounded ethics in the concepts of free will and responsibility. Free will, in his view, did not legitimise all possible actions; rather, it was constrained by moral law, emphasising reciprocity and duty. Whereas Aristotle identified the supreme good with happiness as a theoretical activity aligned with virtue, Kant described the *summum bonum* as the full subordination of humanity to moral law, so that obedience becomes akin to sanctity (Marques & Cadilha, 2019). For both, and indeed for most major moral philosophers, the idea of a “highest good” functioned as the aim of ethical life.

This philosophical lineage continues to resonate in entrepreneurship studies. Costa Gomes (2023) highlights that ethics and happiness are not separate domains but mutually reinforcing, with entrepreneurship becoming a moral endeavour when guided by ethical values. In this sense, ethics provides the pathway to happiness, while entrepreneurial action, when ethically grounded, serves not only economic but also humanistic purposes (Leite, Audretsch & Leite, 2024).

#### **3.2. Contemporary Relevance**

A contemporary example lies in research applied to artificial intelligence and sustainability. Ethical decisions concerning data collection, environmental certification, or corporate accountability illustrate how value judgements shape not only scientific validity but also the social legitimacy of business innovation. Here, as in Political Economy, the researcher (or entrepreneur) acts as a mediator between scientific rigour and social responsibility.

The etymology of *ethics*—from the Greek *ethos* (custom, habit, disposition)—already pointed beyond mere description of morality to a critical stance toward prevailing moral practices. Ethics is not simply about cataloguing norms but about evaluating them, identifying values that are defensible as “real” or “true.” From a philosophical standpoint, ethical reflection must clarify how moral judgements should be made rather than reproduce them uncritically.

#### **3.3. Critical Perspectives**

For Brown (2021), value judgements are “*reflective decisions about what to value, and they are better or worse depending on reasons*” (p. 105). These judgements may be made by individuals, research teams, or entire



scientific communities (p. 64). At the core of values lie practical reasons that justify action: “Valuing is at the heart of action, activity, practice. To value something is to be disposed to act in favour of it” (Brown, 2021, p. 15).

Neves (2019) similarly stresses that “Political Economy ... is a normative science, based on value judgements, which does not prevent it, in his view, from adopting ‘the canons of scientific procedure’ and respecting the requirements of ‘research ethics’ (notably ‘intellectual honesty’), indispensable for the pursuit of objectivity” (p. 208).

Values also encompass multiple dimensions: *biovalues* (e.g., survival, adaptation to the environment), social values (communication, cooperation, trust), cultural values (customs, political convictions, religious beliefs), personal values tied to identity, and institutional virtues such as stability and justice. These may be consciously or unconsciously professed, and they evolve across time and communities.

The supposed ideal of value-freedom thus appears both impractical and undesirable. Human beings are inevitably shaped by motivated reasoning and social influences; values are not external distortions but integral to science. As Brown (2021) argues, “science without values is neither possible nor desirable” (p. 63). Importantly, he distinguishes between unreflective valuing and reasoned value judgements, noting that values—as expressions of needs, goals, and ideals—are not necessarily subjective, arbitrary, or incommunicable. His proposed theory conceptualises values as “inherently tied to action,” deriving from multiple sources and playing diverse roles in experience (Brown, 2021, p. 20).

This recognition foregrounds the ethical character—especially in terms of responsibility—of scientific and entrepreneurial practice. It also affirms that questions of value can and should be debated empirically, as they pertain to practical problems of what ought to be done under circumstances (Brown, 2021, pp. 20–21).

### 3.4. A Novel Framework: Ethics as Epistemic Infrastructure

To advance beyond existing conceptions of value-laden science (e.g., Longino, 1990; Brown, 2021), we propose a formal model of ethics as epistemic infrastructure in political economy and entrepreneurship research. Unlike Longino’s social epistemology, which emphasizes social interactions in knowledge validation, our framework positions ethics as a structural scaffold that integrates cognitive, normative, and practical dimensions of knowledge production. This model comprises three components:

1. Normative Anchors: Ethical values (e.g., justice, inclusion) that define legitimate knowledge sources and priorities in research design.
2. Cognitive Filters: Methodological choices shaped by these values, influencing which data or phenomena are deemed salient.
3. Practical Outputs: The societal impact of research, measured by its alignment with stakeholder needs and distributive outcomes.

Proposition 1: Research programs prioritizing inclusive normative anchors (e.g., addressing marginalized communities) yield higher social legitimacy in entrepreneurial ecosystems, measurable via stakeholder trust metrics (e.g., survey-based trust indices). Proposition 2: Cognitive filters shaped by ethical values (e.g., sustainability) lead to greater innovation diversity, quantifiable through patent heterogeneity or startup mission statements. Proposition 3: Practical outputs aligned with ethical infrastructures enhance long-term ecosystem resilience, evidenced by sustained funding or policy adoption rates.

Operationalisation and research design

*Stakeholder trust* can be measured via (i) validated trust indices adapted to innovation/HEI–industry policy contexts; (ii) triangulation with behavioural proxies (e.g., participation rates in open calls; opt-in rates to data-sharing agreements); and (iii) sentiment analysis of ecosystem communications. *Innovation diversity* can be assessed using (i) patent and publication heterogeneity indices (Shannon/Simpson) at technology-class level; and (ii) supervised textual coding of startup mission statements to capture normative anchors (e.g., inclusion,



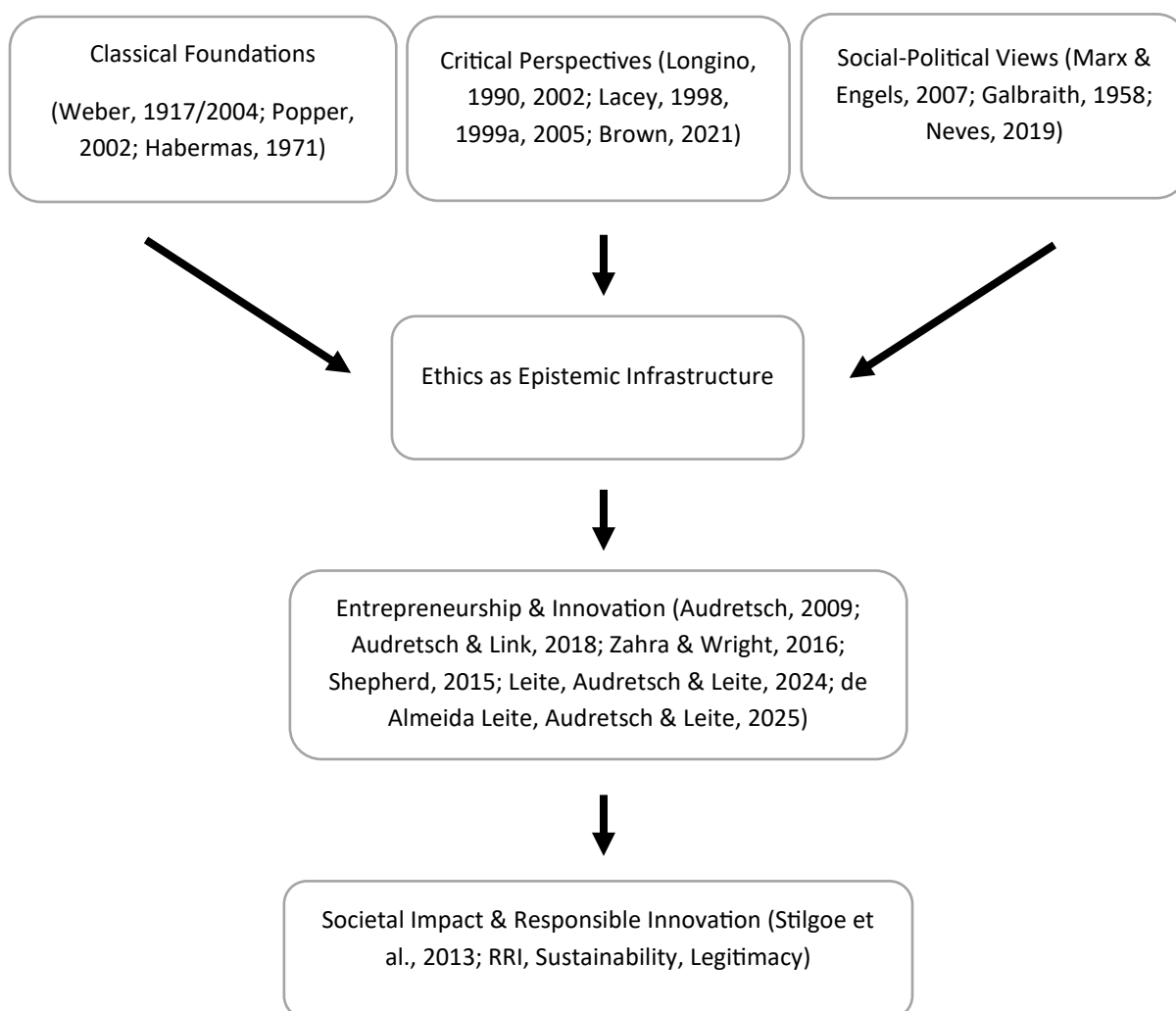
sustainability). *Ecosystem resilience* can be proxied by (i) survival and growth curves of ventures across shocks; (ii) persistence of multi-source funding; and (iii) policy uptake (citations of research in strategies, legislation, or regulatory guidance).

Suggested empirical designs include multi-site panel datasets of regional ecosystems (difference-in-differences with staggered adoption of RRI-like charters), matched-pair case studies (ethics-explicit vs. ethics-implicit accelerators), and mixed-methods process tracing combining archival records with stakeholder interviews and preregistered coding schemes.

Boundary conditions. Effects are likely moderated by institutional quality (rule of law), absorptive capacity (HEI–industry linkages), and social cohesion (inequality indices). We therefore recommend preregistering moderators and robustness checks (placebo tests, alternative outcomes, and sensitivity to model specification).

This framework distinguishes itself by operationalising ethics as a measurable driver of knowledge production—unlike Longino’s broader social focus—and provides a testable agenda for empirical studies in entrepreneurship and political economy.

**Figure 1:** Theoretical foundations and practical implications of ethics as epistemic infrastructure in political economy and entrepreneurship research.



**Source:** Conceptualized by the authors.

Figure 1. Ethics as epistemic infrastructure in political economy and entrepreneurship. Inputs (normative anchors): justice, inclusion, sustainability → Cognitive filters: problem framing, construct choice, method selection, evidence weighting → Processes: peer scrutiny, stakeholder engagement, reflexive iteration (RRI) → Outputs: innovation diversity, stakeholder trust, ecosystem resilience → Feedback loops: policy uptake and societal outcomes update normative anchors. Note: Dashed arrows = moderating effects (institutional quality, absorptive capacity, inequality); solid arrows = primary causal pathways. Sources: Weber (1917/2004); Habermas (1968/1971); Longino (1990, 2002); Lacey (1998, 1999a, 2005); Brown (2021).

As illustrated, the classical foundations (Weber, 1917/2004; Popper, 1959/2002; Habermas, 1968/1971) establish the initial dilemma of values in science. Critical perspectives (Longino, 1990, 2002; Lacey, 1998, 1999a, 2005; Brown, 2021) deconstruct the ideal of neutrality and argue for the legitimisation of values. Socio-political views (Marx & Engels, 2007; Galbraith, 1958; Neves, 2019) expose the power dynamics and ideological struggles inherent in knowledge production. Together, these streams provide the groundwork for understanding ethics not as an external constraint but as a constitutive epistemic infrastructure. This infrastructure, in turn, organises and guides knowledge production in the applied fields of entrepreneurship and innovation (Audretsch, 2009; Audretsch & Link, 2018; Zahra & Wright, 2016; Shepherd, 2015; Leite, Audretsch, & Leite, 2024; de Almeida Leite et al., 2025), ultimately shaping the societal impact and responsible innovation of scientific enterprise.

Ethics today commands growing attention and recognition. Yet it is neither a recent concern nor one confined to contemporary societies, and its role in research remains widely debated. Ethical problems are best understood as the search for truth and for the values underlying decision-making, insofar as inquiry investigates human actions and their natural aspirations for fulfilment. Ethics, then, may be defined as a set of values that guide life and social coexistence. To some extent it is relative, since values are not fixed but shift over historical time.

Accordingly, no single universal norm exists that would allow one to evaluate human actions in research with clarity and precision. Rather, ethical judgement tends to follow the direction of human will be shaped by contextual values. Importantly, values should not play a concealed role in the acceptance or rejection of theories. On the contrary, controversies over values will increasingly become part of the global discourse of the scientific community, as scientists retain the freedom to adopt approaches that may serve the interests of marginalised groups such as poorer countries or minorities (Lacey, 1998). As Lacey (1999a) further warns, one must avoid the risk that “specialisation” obscures shared perspectives on values, even if unconsciously held within the scientific community.

In truth, there is no definitive answer to the questions posed in this essay; what emerges instead are certain insights that may contribute to improving processes of ethical judgement. The challenge here has not been to define what ethics *is*, nor to classify what constitutes “truth,” but to reflect on the evidence of ethics as illustrated.

For Political Economy and entrepreneurship scholars, this implies explicitly theorising which knowledge sources are legitimised in opportunity recognition (Audretsch & Link, 2018) and which social roles of entrepreneurship are being normatively advanced (Zahra & Wright, 2016)—and with what distributive and ethical consequences. Doing so clarifies how values inform methodological choices, policy prescriptions, and impact claims. This reframes ethics not as an afterthought but as an analytical lens that reveals the normative underpinnings of entrepreneurial ecosystems.

For policymakers and ecosystem builders, this implies moving beyond simplistic metrics of innovation (e.g., number of startups, patents) towards evaluating the *quality* of entrepreneurship in terms of its normative orientation and distributive outcomes. Frameworks like Responsible Research and Innovation (RRI) offer tools for such an evaluation, emphasizing anticipation, inclusion, reflexivity, and responsiveness (Stilgoe et al., 2013).



Science without ethics—or rather without values—would make little sense, and indeed risks generating far greater social harms. Scientists must therefore acknowledge the contingencies of their work as unforced choices, identify the morally salient features of the situations they confront, empathically recognise legitimate stakeholders, reconstruct and imaginatively explore alternative possibilities, and formulate fair and reasoned value judgements to guide their decisions (Brown, 2021, p. 21).

Ultimately, in Weber's words, the ethic of the scientist should be a commitment to truth. Yet this commitment is not always a commitment to the good. Human beings often follow those values that serve them best, weighing advantages and disadvantages at every step. Ethics thus remains a value—but frequently not the decisive one—particularly when survival is at stake.

We therefore propose understanding ethics not as an external restriction upon science, but as an epistemic infrastructure that organises and orients the production of knowledge in Political Economy and entrepreneurship studies. Such an approach enables not only greater scientific rigour but also heightened social relevance, by connecting values with innovation and responsibility.

Consequently, the absence of ethical reflection in science and entrepreneurship risks legitimising harmful practices—exacerbating inequality, enabling exclusionary innovation, or fuelling greenwashing under the guise of progress. Similar concerns emerge in digital health, where AI-driven innovations challenge the adequacy of informed consent and demand new normative safeguards. As Costa Gomes (2025) argues, reconfiguring bioethical frameworks in the age of artificial intelligence underscores that ethical reflection is not an optional add-on but a prerequisite for scientific and social legitimacy. By contrast, recognising ethics as constitutive of knowledge production ensures that innovation not only advances scientific frontiers but also contributes to a more just, inclusive, and sustainable society.

#### **4. Conclusion and Future Research**

This essay has framed ethics as an epistemic infrastructure integral to knowledge production in political economy and entrepreneurship, moving beyond Weber's (1917/2004) value-neutrality to embrace values as constitutive drivers of rigorous and socially relevant science. Drawing on critical perspectives (e.g., Longino, 1990; Brown, 2021), it argues that ethical commitments shape legitimate knowledge and socially acceptable innovation, offering a novel lens for understanding entrepreneurial ecosystems.

To extend this contribution, future research should empirically test the epistemic infrastructure framework through targeted, high-impact questions:

1. **AI-Driven Entrepreneurship:** How do ethical values (e.g., transparency, fairness) influence opportunity recognition in AI-driven startups in emerging economies, and what are the distributive consequences for local communities? Mixed-methods studies combining econometric analyses of startup performance with qualitative stakeholder interviews could yield insights publishable in *Research Policy*.
2. **Ethical Resilience in Ecosystems:** How do normative anchors (e.g., sustainability commitments) enhance entrepreneurial ecosystem resilience during crises like climate disruptions? Longitudinal case studies in regions like Sub-Saharan Africa, measuring startup survival rates, could attract attention in *Journal of Business Venturing*.
3. **Policy Alignment with SDGs:** How can ethical infrastructures in political economy research inform policymaking to align innovation with UN Sustainable Development Goals (e.g., SDG 10—Reduced Inequalities)? Comparative policy analyses across developed and developing nations could enhance global relevance, targeting *Journal of Management Studies*.

These questions operationalize Responsible Research and Innovation (RRI) principles (Stilgoe et al., 2013), aligning with UNESCO's science-ethics guidance and SDGs (e.g., SDG 9—Industry, Innovation and Infrastructure). Complementary approaches, such as ethnographies of innovation hubs or experimental designs testing ethical frameworks (Parks-Leduc, 2021), can further map how values shape knowledge production in practice. This



agenda not only enriches the epistemology of science but also strengthens the alignment between innovation, responsibility, and societal impact, promising high citation potential and policy relevance.

As a conceptual contribution, this essay paves the way for empirical studies to investigate how ethical commitments concretely shape entrepreneurial ecosystems, ensuring both scholarly rigor and practical dividends for a just, inclusive, and sustainable future.

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## Unpaid work and mental health during a pandemic: Evidence from the UK


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### Abstract

We examine the impact of unpaid work on mental health during the COVID-19 pandemic using a rich longitudinal survey data from the UK. We find that the pandemic significantly increased mental health problems, particularly among women. Our study also reveals that increased hours of unpaid work, including housework and caregiving are associated with worsening mental health outcomes for both men and women. These findings highlight the urgent need for policies addressing the mental health burden of unpaid labor during crises.

**Keywords:** COVID-19; Gender Disparities; Mental Health; Social Work; Unpaid Work.

### 1. Introduction

Mental health has become one of the most pressing challenges of the 21<sup>st</sup> century. Beyond the demands of an increasingly complex and rapidly changing society, recent economic crises and natural disasters have further exacerbated mental health disorders. Studies show that problems such as depression, anxiety, substance abuse, suicidal behaviour, and post-traumatic stress often emerge after major crises (Chaves et al., 2013). The COVID-19 pandemic was no exception. It generated unprecedented challenges with global repercussions, intensifying not only concerns about physical health but also the prevalence of mental health problems (OECD, 2021; Santomauro et al., 2021).

This study uses a comprehensive longitudinal dataset that spans the period before, during, and after the pandemic to examine key mental health issues arising from COVID-19. Prior research suggests that women may experience poorer psychological outcomes than men during crises (e.g., González-Sanguino et al., 2020; Özdin & Bayrak Özdin, 2020). We therefore assess whether women reported higher levels of mental health problems than men as a result of the pandemic. Given the rise in unpaid work during this period, we also investigate whether such tasks contributed to deteriorating mental health.

The relevance of these questions goes beyond individual well-being. Mental health and the unequal distribution of unpaid work are closely linked to economic productivity, entrepreneurship, and innovation. High levels of psychological distress undermine creativity, risk-taking, and resilience—traits essential for entrepreneurial activity. At the same time, excessive unpaid work, particularly for women, may restrict time and energy for entrepreneurial initiatives or innovative work, thereby exacerbating gender disparities in business creation and career advancement. Understanding these dynamics is therefore critical not only for public health policy but also for fostering inclusive and sustainable economic development.

Our approach compares the same individuals' mental health before and during/after the pandemic (paired samples). Unlike many studies based on short-term surveys, our analysis relies on data collected over an extended period of the pandemic, officially declared over by the World Health Organization in May 2023. This broader time horizon enables more robust conclusions about the impact of unpaid work on mental health.



The findings underscore the urgent need for policies aimed at reducing the mental health burden of unpaid work during crises, which are increasingly likely in the future. Such policies are also crucial for sustaining workforce productivity, supporting entrepreneurial activity, and encouraging innovation.

The paper is structured as follows: Section 2 presents the literature review; Section 3 outlines the data and methodology; Section 4 reports the results and discussion; and Section 5 provides conclusions.

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## 2. Literature Review

Several studies have examined the mental health consequences of the COVID-19 pandemic. However, this study is the first to use a comprehensive longitudinal dataset covering the period before, during, and after the pandemic. We first test whether mental health problems increased during the pandemic (Hypothesis H1). Previous research suggests that women may experience poorer psychological outcomes than men (e.g., González-Sanguino et al., 2020; Özdin & Bayrak Özdin, 2020). Accordingly, Hypothesis H2 assesses whether women reported higher levels of mental health problems.

One of the main explanations advanced in the literature concerns the overload of unpaid work. Unpaid work is defined as all services performed within the household for its members without financial compensation, such as housework and caregiving (Pinquart & Sörensen, 2007; Vitaliano, 2003). The concept of role overload (Robinson & Spitze, 1992) holds that human energy is limited: when individuals perform multiple roles simultaneously, the likelihood of strain and adverse effects on health increases. This mechanism became particularly evident during the pandemic, when lockdowns, restrictions on movement, school closures, and social distancing sharply expanded unpaid tasks.

Evidence shows that women were especially affected (Xue & McMunn, 2021; OECD, 2021; Alfonzo et al., 2023; Madia et al., 2023). During the lockdown period, they devoted significantly more hours to childcare and household responsibilities, often reducing paid working hours to accommodate these demands (Xue & McMunn, 2021). Men also increased their involvement in unpaid work, but the imbalance in household responsibilities remained, leading to mental health deterioration in both genders. On this basis, Hypothesis H3 proposes that unpaid work negatively affects the mental health of men and women alike.

Another strand of literature highlights fairness and equity in the division of household tasks. Unequal or unfair distributions of unpaid work are associated with greater psychological distress (Robinson & Spitze, 1992). Moreover, the low prestige attributed to household work, its physically demanding nature, and the fact that it is often performed in isolation further contribute to its negative impact on well-being. While these issues are not explored in depth in this paper, they remain relevant for future research.

This study contributes to the literature by comparing the same individuals' mental health before and during/after the COVID-19 pandemic (paired samples). Unlike other analyses that rely on surveys collected over a short period, our data span a large part of the pandemic (which the World Health Organization declared officially over in May 2023). This extended timeframe allows for more robust conclusions about the impact of unpaid work on mental health.

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## 3. Methods

### 3.1. Data

We conduct our empirical analysis using data from *Understanding Society*, a longitudinal household panel survey that provides evidence on life in the United Kingdom. The study, based at the Institute for Social and Economic Research at the University of Essex, has been conducted annually since 2009 and covers a wide range of social, economic, and behavioural dimensions.

For this paper, we use data from Waves 10 and 12 of the main survey. The questionnaires were administered either face-to-face or by telephone. Wave 10 contains data from 34,318 participants interviewed between



January 2018 and May 2020, while Wave 12 is composed of 29,270 respondents interviewed between January 2020 and May 2022.

After combining the two waves, we ensured that all participants were in paid work in both periods. Applying this restriction, we obtained a final sample of 9,997 individuals (3,997 men, representing 43.5%, and 5,200 women, representing 56.5%). The participants' age at the beginning of the Wave 10 interviews ranged from 18 to 69 years, with a mean of 43.31 years (SD = 12.04).

### **3.2. Measuring Instruments**

The General Health Questionnaire (GHQ-12), developed by Goldberg (1972), is a widely used instrument for detecting psychological distress (Hystad & Johnsen, 2020). Designed as a screening tool, it identifies individuals who probably have, or are at risk of developing, psychiatric disorders. It measures a range of mental health issues, including depression, anxiety, somatic symptoms, and social withdrawal (Jackson, 2007).

The GHQ-12 consists of 12 questions, each assessed on a 4-point Likert scale (see Table 1 for item descriptions). In this study, each item was recoded to take values from 0 to 3 points (0, 1, 2, 3), with 0 assigned to the least symptomatic response and 3 to the most symptomatic response. Higher scores indicate poorer mental health, while lower scores reflect better mental health (Andrich & van Schoubroeck, 1989).

In addition, we applied a binary scoring method (0, 0, 1, 1). For each item, 0 was given to the two least symptomatic responses and 1 to the two most symptomatic responses. The binary scores were then summed across the 12 items, producing a total score between 0 and 12. A lower total score indicates better mental health, while a higher score suggests a greater likelihood of mental disorders (Bell et al., 2005).

Following the recommended cut-off of 3/4 (Hatton et al., 2017), respondents with scores above 3 were classified as GHQ positive (probable psychiatric disorder), while those scoring 3 or below were classified as GHQ negative (Hayes, 2014).

**Table 1:** General health questionnaire (GHQ-12).

GHQ1 — <b>Concentration:</b> Have you recently been able to concentrate on whatever you're doing? (1- Better than usual; 2- Same as usual; 3- Less than usual; 4 - Much less than usual)
GHQ2 — <b>Loss of sleep:</b> Have you recently lost much sleep over worry? (1- Not at all; 2- No more than usual; 3- Rather more than usual; 4- Much more than usual)
GHQ3 — <b>Playing a useful role:</b> Have you recently felt that you were playing a useful part in things? (1- More so than usual; 2- Same as usual; 3- Less so than usual; 4- Much less than usual)
GHQ4 — <b>Capable of making decisions:</b> Have you recently felt capable of making decisions about things? (1- More so than usual; 2- Same as usual; 3- Less so than usual; 4- Much less capable)
GHQ5 — <b>Constantly under strain:</b> Have you recently felt constantly under strain? (1- Not at all; 2- No more than usual; 3- Rather more than usual; 4- Much more than usual)
GHQ6 — <b>Problem overcoming difficulties:</b> Have you recently felt you couldn't overcome your difficulties? (1- Not at all; 2- No more than usual; 3- Rather more than usual; 4- Much more than usual)
GHQ7 — <b>Enjoy day-to-day activities:</b> Have you recently been able to enjoy your normal day-to-day activities? (1- More so than usual; 2- Same as usual; 3- Less so than usual; 4- Much less than usual)
GHQ8 — <b>Ability to face problems:</b> Have you recently been able to face up to problems? (1- More so than usual; 2- Same as usual; 3- Less able than usual; 4- Much less able)
GHQ9 — <b>Unhappy or depressed:</b> Have you recently been feeling unhappy or depressed? (1- Not at all; 2- No more than usual; 3- Rather more than usual; 4- Much more than usual)
GHQ10 — <b>Losing confidence:</b> Have you recently been losing confidence in yourself? (1- Not at all; 2- No more than usual; 3- Rather more than usual; 4- Much more than usual)
GHQ11 — <b>Believe worthless:</b> Have you recently been thinking of yourself as a worthless person? (1- Not at all; 2- No more than usual; 3- Rather more than usual; 4- Much more than usual)
GHQ12 — <b>General happiness:</b> Have you recently been feeling reasonably happy, all things considered? (1- More so than usual; 2- About the same as usual; 3- Less so than usual; 4- Much less than usual)

**Source:** Own elaboration.

Although originally developed as a unidimensional construct, exploratory analyses in several studies have revealed two- or three-factor structures (Hystad & Johnsen, 2020).

### 3.3. Data Analysis

In the first step, we combined Waves 10 and 12 into a single database. All statistical analyses were performed using IBM SPSS Statistics 28. The individual identification code allowed us to pair responses from the two waves, excluding participants who did not respond in either. Under these conditions, the dataset comprised 26,095 individuals.

To define two temporal periods—before the pandemic and during/after the pandemic—Wave 10 included only interviews conducted up to 31 January 2020, while Wave 12 included only participants who responded from 1 February 2020 onwards (the first case of COVID-19 in the UK was detected on 31 January 2020). At this stage, the database contained 24,606 participants. We then restricted the sample to individuals who were in paid work in both waves and who answered all 12 GHQ-12 items. After applying these restrictions, the final sample consisted of 9,197 individuals.



To characterize participants, we analyzed absolute and relative frequencies (percentages). For the quantitative variable age, we report minimum, maximum, mean, and standard deviation.

Following Kline (2016), item sensitivity was assessed using skewness ( $|Sk| \leq 3$ ) and kurtosis ( $|Ku| \leq 10$ ). The suitability of applying exploratory factor analysis (EFA) to the GHQ-12 construct was evaluated using the Kaiser-Meyer-Olkin (KMO) sample adequacy index (values greater than 0.8 indicate good adequacy) and Bartlett's test of sphericity ( $p < 0.05$ ) (Pestana & Gageiro, 2014).

We applied the principal components method to extract factors, retaining factor loadings above 0.50 (Hair et al., 2014). Varimax rotation and the Kaiser criterion (eigenvalues greater than 1) were used to determine the number of factors to retain. Reliability of the GHQ-12 items was assessed using Cronbach's alpha, with values above 0.7 considered acceptable (Hair et al., 2014). Correlations between GHQ-12 factors were analyzed using Pearson's correlation. To test hypotheses, we employed the Student's t-test for paired samples and the Student's t-test for independent samples. Statistical significance was set at  $p < 0.05$  (Marôco, 2018).

## 4. Findings and Discussion

### 4.1. Factor Analysis and Reliability

The skewness and kurtosis coefficients of the GHQ-12 items show absolute values below 1.80 and 7.32, respectively, and therefore fall within the parameters defined by Kline (2016). To assess the adequacy of the data for factor analysis, Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) index were applied to both Wave 10 and Wave 12. The results confirm good suitability for exploratory factor analysis (Wave 10:  $\chi^2(66) = 51,237.268$ ,  $p < 0.001$ , KMO = 0.930; Wave 12:  $\chi^2(66) = 55,382.292$ ,  $p < 0.001$ , KMO = 0.930), consistent with the recommendations of Pestana and Gageiro (2014).

The exploratory factor analysis of the 12 GHQ-12 items revealed a two-factor structure in both waves (Table 2). Together, these factors explained 58.88% of the total variance in Wave 10 and 59.96% in Wave 12. The first factor, labelled *General Dysphoria* (items 2, 5, 6, 9, 10, and 11), explained 32.07% of the variance in Wave 10 and 32.52% in Wave 12. This factor includes items primarily related to anxiety and depression. The second factor, labelled *Social Dysfunction* (items 1, 3, 4, 7, 8, and 12), explained 26.81% of the variance in Wave 10 and 27.44% in Wave 12. This two-factor structure is consistent with previous findings (Centofanti et al., 2019).

Cronbach's alpha for the full 12-item GHQ-12 was 0.900 in Wave 10 and 0.906 in Wave 12. The Cronbach's alpha values for the two factors in both waves exceeded 0.80, which, according to Hair et al. (2014), indicates high internal consistency. These results support the reliability of the GHQ-12 for assessing mental health in this sample and are consistent with earlier studies (Centofanti et al., 2019; Politi et al., 1994).

**Table 2:** Results of applying factorial analysis to GHQ-12 in waves 10 and 12.

Items	Wave 10		Wave 12	
	Factor 1	Factor 2	Factor 1	Factor 2
GHQ1: concentration		0.55		0.57
GHQ2: loss of sleep	0.72		0.72	
GHQ3: playing a useful role		0.71		0.75
GHQ4: capable of making decisions		0.78		0.80
GHQ5: constantly under strain	0.76		0.80	
GHQ6: problem overcoming difficulties	0.76		0.78	
GHQ7: enjoy day-to-day activities		0.66		0.56
GHQ8: ability to face problems		0.71		0.72
GHQ9: unhappy or depressed	0.80		0.78	
GHQ10: losing confidence	0.76		0.75	
GHQ11: believe worthless	0.66		0.63	
GHQ12: general happiness		0.63		0.63
Eigenvalues	3.85	3.22	3.90	3.29
% Explained variance	32.07	26.81	32.52	27.44
Cronbach's alpha	0.883	0.826	0.889	0.824

**Source:** Own elaboration.

The correlation between the two factors of the GHQ-12 was positive and significant ( $p < 0.001$ ) in both waves (Wave 10:  $r = 0.809$ ; Wave 12:  $r = 0.811$ ). This strong correlation (Marôco, 2018) indicates that higher levels of anxiety and depression are associated with greater difficulties in carrying out daily activities and coping with problems.

#### 4.2. Mental Health Comparison Between Waves

Table 3 presents the GHQ-12 items during/after the pandemic (Wave 12). Mental health indicators worsened compared to the pre-pandemic period (Wave 10), supporting the evidence that COVID-19 contributed to a rise in mental health problems. The Student's  $t$ -test for paired samples shows that the increase was statistically significant for almost all items, except for item 10 (losing confidence). Therefore, there is strong statistical evidence that the pandemic exacerbated mental health problems, which provides partial support for Hypothesis 1.

In the UK, the maintenance of confidence during and after the pandemic may be explained by higher investment in mental health services, awareness campaigns, the expansion of online support services, stronger community networks, and government initiatives to protect workers and provide financial assistance.



**Table 3:** Results of the comparison of GHQ-12 between waves 10 and 12.

Items	Wave	<i>M</i>	<i>SD</i>	<i>t</i> test
GHQ1: concentration	12	1.19	0.49	7.79***
	10	1.14	0.47	
GHQ2: loss of sleep	12	0.91	0.76	9.48***
	10	0.83	0.72	
GHQ3: playing a useful role	12	1.08	0.51	6.36***
	10	1.04	0.49	
GHQ4: capable of making decisions	12	1.07	0.40	8.35***
	10	1.02	0.41	
GHQ5: constantly under strain	12	1.07	0.76	2.40**
	10	1.05	0.73	
GHQ6: problem overcoming difficulties	12	0.80	0.72	3.53***
	10	0.77	0.71	
GHQ7: enjoy day-to-day activities	12	1.25	0.60	17.93***
	10	1.12	0.49	
GHQ8: ability to face problems	12	1.08	0.41	6.09***
	10	1.05	0.43	
GHQ9: unhappy or depressed	12	0.93	0.80	6.81***
	10	0.87	0.78	
GHQ10: losing confidence	12	0.77	0.78	0.51
	10	0.76	0.78	
GHQ11: believe worthless	12	0.46	0.70	4.72***
	10	0.43	0.68	
GHQ12: general happiness	12	1.14	0.56	10.14***
	10	1.06	0.54	

**Note:** \*\*\* $p < 0.001$ , \*\* $p < 0.01$ . **Source:** Own elaboration.

Table 4 reports the results of the Student’s *t*-test for independent samples (by gender). The findings provide robust evidence that women had significantly poorer average mental health outcomes than men in both waves ( $p < 0.001$ ), thus empirically supporting Hypothesis 2. We argue that the disproportionate burden of unpaid work during the COVID-19 pandemic intensified women’s mental health disorders. Most of the additional workload linked to COVID-19 fell on women (Del Boca et al., 2022), particularly childcare due to school closures and caring for sick family members, which contributed to higher levels of psychological distress.

**Table 4:** Results of the comparison of GHQ-12 between gender in Waves 10 and 12.

Wave	Items	Male (n = 3997)		Female (n = 5200)		t test
		M	SD	M	SD	
10	GHQ1: concentration	1.10	0.43	1.17	0.49	-8.19***
	GHQ2: loss of sleep	0.74	0.70	0.90	0.73	-10.79***
	GHQ3: playing a useful role	1.02	0.48	1.05	0.50	-3.66***
	GHQ4: capable of making decisions	0.99	0.39	1.04	0.42	-5.74***
	GHQ5: constantly under strain	0.99	0.71	1.09	0.74	-6.60***
	GHQ6: problem overcoming difficulties	0.72	0.68	0.80	0.72	-5.78***
	GHQ7: enjoy day-to-day activities	1.09	0.47	1.14	0.50	-4.84***
	GHQ8: ability to face problems	1.02	0.40	1.08	0.46	-6.86***
	GHQ9: unhappy or depressed	0.80	0.75	0.93	0.79	-7.89***
	GHQ10: losing confidence	0.65	0.74	0.85	0.80	-11.93***
	GHQ11: believe worthless	0.37	0.64	0.47	0.71	-6.81***
	GHQ12: general happiness	1.04	0.51	1.08	0.56	-3.81***
12	GHQ1: concentration	1.14	0.44	1.23	0.52	-9.24***
	GHQ2: loss of sleep	0.78	0.72	1.02	0.77	-14.95***
	GHQ3: playing a useful role	1.05	0.48	1.10	0.54	-4.56***
	GHQ4: capable of making decisions	1.03	0.37	1.09	0.43	-6.49***
	GHQ5: constantly under strain	0.96	0.72	1.15	0.78	-12.35***
	GHQ6: problem overcoming difficulties	0.73	0.67	0.85	0.74	-7.86***
	GHQ7: enjoy day-to-day activities	1.20	0.56	1.29	0.62	-7.20***
	GHQ8: ability to face problems	1.06	0.37	1.11	0.44	-5.85***
	GHQ9: unhappy or depressed	0.84	0.77	1.00	0.82	-9.39***
	GHQ10: losing confidence	0.64	0.72	0.86	0.81	-14.02***
	GHQ11: believe worthless	0.40	0.65	0.51	0.74	-7.30***
	GHQ12: general happiness	1.11	0.51	1.16	0.59	-4.95***

**Note:** \*\*\*  $p < 0.001$ . **Source:** Own elaboration.

#### 4.3. Classification of Individuals Regarding Mental Health

There are also statistically significant differences in the GHQ-12 construct (Wave 10:  $M = 1.65$ ,  $SD = 2.90$ ; Wave 12:  $M = 1.98$ ,  $SD = 3.13$ ,  $t(9196) = 9.10$ ) and its factors: General Dysphoria (Wave 10:  $M = 0.93$ ,  $SD = 1.60$ ; Wave 12:  $M = 1.04$ ,  $SD = 1.69$ ,  $t(9196) = 5.89$ ) and Social Dysfunction (Wave 10:  $M = 0.73$ ,  $SD = 1.45$ ; Wave 12:  $M = 0.94$ ,  $SD = 1.60$ ,  $t(9196) = 11.28$ ). These results imply that the COVID-19 pandemic affected individuals' mental health.

Table 5 shows there were around 13.5 per cent ( $n = 548$ ) males and 20.1 per cent ( $n = 1068$ ) females with a score above 3 before Covid-19 (Wave 10). Since the number of cases increased with the pandemic, we observe that in Wave 12 we have 15.3% ( $n = 619$ ) of males and 24.8% ( $n = 1320$ ) of females. This implies that, overall, before the pandemic 17.6% of individuals had mental health problems (GHQ-12) and during the pandemic the percentage increased to 21.1%.

**Table 5:** Distribution of individuals by wave, by sex and by total GHQ-12 score.

Score	Wave 10 Male (n = 3997)		Female (n = 5200)		Wave 12 Male (n = 3997)		Female (n = 5200)	
	n	%	n	%	n	%	n	%
0	2560	64.0	2861	55.02	2424	60.6	2427	46.7
1	503	12.6	679	13.06	513	12.8	765	14.7
2	246	6.2	379	7.29	257	6.4	403	7.8
3	140	3.5	213	4.10	184	4.6	285	5.5
4	110	2.8	160	3.08	125	3.1	250	4.8
5	92	2.3	164	3.15	93	2.3	173	3.3
6	64	1.6	142	2.73	65	1.6	154	3.0
7	53	1.3	122	2.35	60	1.5	144	2.8
8	67	1.7	118	2.27	66	1.7	141	2.7
9	43	1.1	109	2.10	66	1.7	115	2.2
10	38	1.0	80	1.54	43	1.1	100	1.9
11	43	1.1	98	1.88	56	1.4	111	2.1
12	38	1.0	75	1.44	45	1.1	132	2.5

**Source:** Own elaboration.

The individuals were classified in the two waves as follows: with a GHQ-12 score above 3 they were referred as GHQ positive; and with a score of less than or equal to 3 they were named GHQ negative. Table 6 highlights that 1218 individuals (402 men and 816 women) before the COVID-19 were classified as GHQ negative, and after/during the pandemic were classified as GHQ positive.

**Table 6:** Crossing of classifications in the two waves.

Wave 10	Gender	Classification	Wave 12		Total
			GHQ Negative	GHQ Positive	
	Male	GHQ Negative	3047	402	3449
		GHQ Positive	331	217	548
		Total	3378	619	3997
	Female	GHQ Negative	3316	816	4132
		GHQ Positive	564	504	1068
		Total	3880	1320	5200

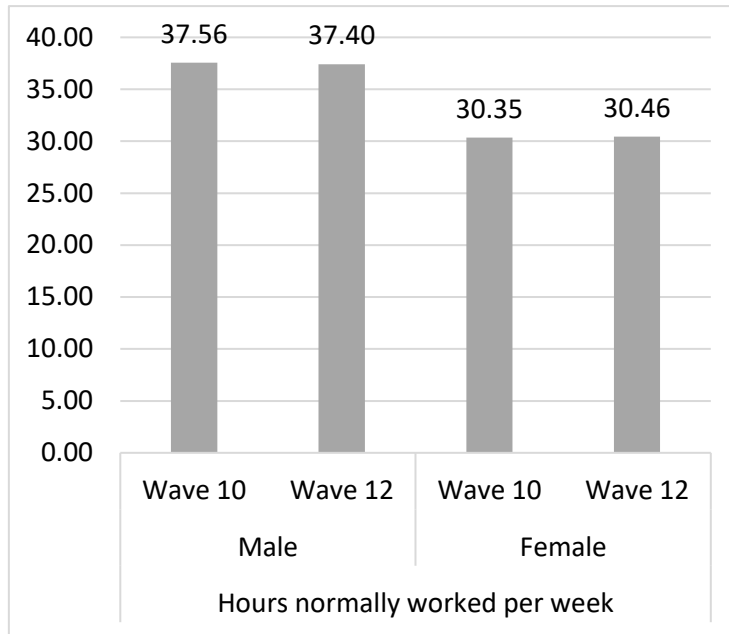
**Source:** Own elaboration.

#### 4.4. Mental Health and Unpaid Work

Figure 1 shows the number of paid hours that individuals worked per week in waves 10 and 12, by gender. With regard to men, in sample terms, the average number of hours of paid work per week decreased from Wave 10 (M = 37.56, SD = 8.61) to 12 (M = 37.40, SD = 8.31). However, this difference is not statistically significant ( $t(3996) = -1.31, p > 0.05$ ). In what it relates to women, the number of paid hours increased from 30.35 (SD = 10.11) in Wave 10 to 30.46 (SD = 9.95) in Wave 12, but the increase was not statistically significant ( $t(5199) = 0.98, p > 0.05$ ).



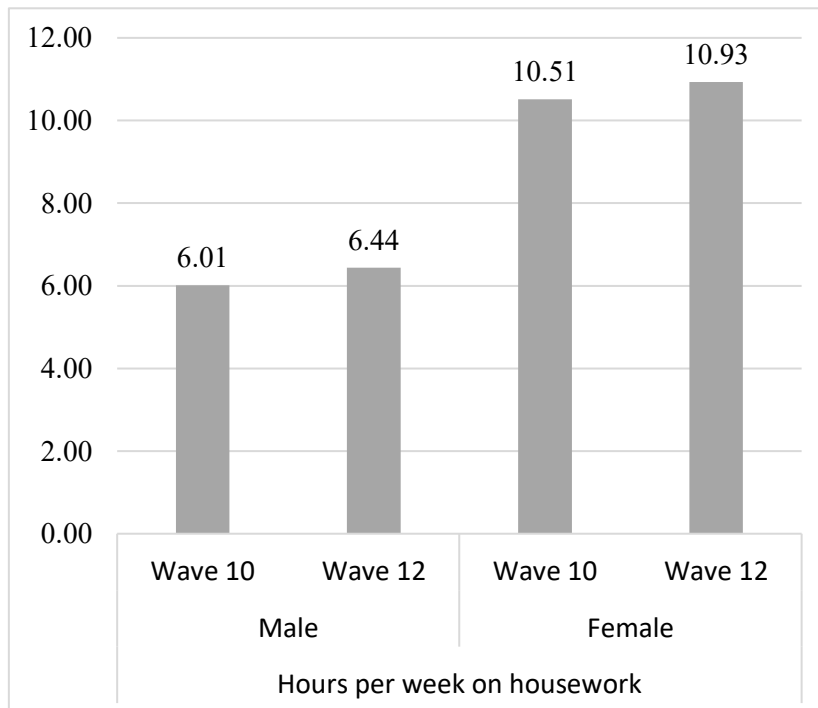
Figure 1: Number of hours normally worked per week in Waves 10 and 12.



Source: Own elaboration.

Figure 2 shows the number of hours per week dedicated to housework in waves 10 and 12, by gender. The number of hours per week that men dedicated to housework increased significantly ( $t(3996) = 4.79, p < 0.001$ ) from Wave 10 ( $M = 6.01, SD = 5.15$ ) to 12 ( $M = 6.44, SD = 5.31$ ). In what it relates to women, the number of hours dedicated to housework also increased significantly ( $t(5199) = 4.03, p < 0.001$ ). The number of hours dedicated to housework in Wave 10 was approximately 10.51 ( $SD = 7.33$ ) and increased in Wave 12 to 10.93 ( $SD = 7.70$ ).

Figure 2: Number of hours per week on housework in Waves 10 and 12.



Source: Own elaboration.



In order to analyze whether unpaid work affects mental health we divided the sample into two groups. We follow this procedure because the number of hours of unpaid work and mental health problems increased with the pandemic: Cluster 1 is made up of individuals whose number of hours dedicated to domestic work per week increased from Wave 10 to Wave 12, and Cluster 2 is made up of the remaining individuals who were not in these conditions.

Table 7 shows that individuals in Cluster 1 have worse mental health (i.e., those with higher levels of both the General Dysphoria and Social Dysfunction and with a higher value in the GHQ-12 construct that analyses mental health). Through the application of the Student’s t-test to compare independent samples, we can conclude that an increase in the number of hours of unpaid work (hours dedicated per week to housework and taking care of disable people or other people at home) affects mental health of both men and women, which empirically supports Hypothesis 3. It is important to highlight that in what relates to Social Dysfunction, there are not significant differences in the men’s group.

**Table 7:** Results of the comparative analysis between unpaid work and mental health.

		Unpaid work clusters						
		Cluster 1			Cluster 2			<i>t test</i>
Gender	Variables	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>	
Male	General Dysphoria	1854	0.83	1.52	2143	0.74	1.49	1.82*
	Social Dysfunction	1854	0.77	1.43	2143	0.71	1.40	1.50
	GHQ-12 Total	1854	1.60	2.81	2143	1.45	2.74	1.75*
Female	General Dysphoria	2427	1.31	1.85	2773	1.19	1.75	2.38**
	Social Dysfunction	2427	1.17	1.75	2773	1.04	1.67	2.57**
	GHQ-12 Total	2427	2.47	3.43	2773	2.23	3.26	2.60**

**Note:** \*\* $p < 0.01$ , \* $p < 0.05$ . **Source:** Own elaboration.

### 5. Conclusion

This study provides robust evidence that the increase in unpaid work during the COVID-19 pandemic contributed to the worsening of mental health. Women were disproportionately affected, given their pre-existing heavier share of household and caregiving responsibilities. This additional burden intensified their psychological distress compared with men.

At the same time, our findings confirm that unpaid work exerts a negative impact on mental health for both men and women. The increase in unpaid hours during the pandemic was associated with higher levels of general dysphoria and social dysfunction, reflecting the strain of combining multiple roles under crisis conditions.

These findings carry important policy implications. Targeted measures are needed to reduce the mental health burden of unpaid work, including better support systems, a fairer division of domestic tasks, and expanded access to mental health services. Workplace policies must also adapt to the reality of increased caregiving and household responsibilities during crises.

Nevertheless, the study has limitations that should be acknowledged. First, the analysis relies on self-reported data, which may be affected by subjective bias. Second, the sample was restricted to individuals in paid employment across both waves, excluding unemployed and informal workers who may have experienced even greater challenges. Third, the study is based on the UK context, which limits the external validity of the findings



to other countries with different welfare regimes or cultural norms. Finally, while the theoretical framework highlights role overload and fairness, additional variables could strengthen the analysis and provide a more comprehensive understanding.

Future research should therefore extend the analysis to different labour market groups and cultural contexts, and include objective measures of workload and fairness in task distribution. Long-term longitudinal studies are also needed to examine whether the effects identified persist beyond the pandemic.

Overall, this work contributes to the literature by showing that the COVID-19 pandemic has deepened gender disparities in unpaid work and mental health. Addressing these challenges requires coordinated policy responses, societal awareness, and organisational innovation. By mitigating the mental health consequences of unpaid work, we can foster individual well-being and social resilience during and beyond global crises.

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## Innovation in the financial sector: An analysis of the use of blockchain technology in financial institutions in Portugal


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### Abstract

In recent years, technological advancements and the history of fraud instances involving financial institutions have resulted in a surge in interest in blockchain technology. Consumers have shown increased interest in and demand for cutting-edge services including new investment options, quicker foreign transfers, and alternative payment methods.

The global financial system might undergo substantial changes as a result of DeFi (decentralized finance). Financial institutions should thus think about putting forward-thinking business ideas into practice and strategically positioning themselves in this quickly expanding market for digital assets.

In addition to assessing the potential advantages of implementation, this study will look into the ideas and methods employed by the banking industry in relation to blockchain adoption. Blockchain is a game-changing technology that could greatly increase financial industry transparency and trust. Among its main advantages are smart contracts, cost savings, enhanced security and efficiency, quicker transfer times and better information quality, and the development of new consumer services.

Regarding the methodology used, an online questionnaire survey was conducted to understand the willingness of financial institution customers to use services based on blockchain technology. The study sample consists of 168 respondents, and the survey results indicate that, in general, customers are receptive to the use of new services based on this technology. In other words, financial institutions observing these trends should follow the path of innovation and implement strategies that enable the adoption of blockchain technology to ensure the continued satisfaction and trust of their customers, strengthen their competitive position, and avoid being overtaken by the competition.

**Keywords:** Blockchain; Efficiency; Financial Institutions; Security; Technology.

### 1. Introduction

The topic was selected in light of the recent discovery that payment methods are becoming more varied and less traditional. Understanding how financial institutions may adopt and use blockchain technology into their everyday operations is crucial since it supports these new payment options.

Blockchain technology and decentralized finance (DeFi) are transforming global access to financial institutions by eliminating regional limitations. By eliminating the need for middlemen, these technologies enable individuals in developing countries without access to traditional banking services to get essential financial services including investments, savings accounts, and loans. Regardless of geographic limitations, anybody may participate in the digital economy with just a smartphone.

Blockchain is a revolutionary technology that has several advantages and has a direct influence on financial institutions. One of the main advantages of using this technology is security. Advanced encryption and a decentralized network protect information and transactions, greatly reducing the possibility of fraud and



cyberattacks. Transparency is still another important advantage since all of the records are maintained in an unalterable public ledger.

There are numerous applications for this technology in the financial sector. Simplifying and expediting cross-border payments while lowering related expenses is one example. Furthermore, enhancing KYC (Know Your Customer) procedures fortifies the defenses against terrorist financing and money laundering. By using smart contracts to automate contract compliance, the banking sector can save time and money. Finally, blockchain enables the transition to more efficient processes, improving the information quality.

This study aims to understand how blockchain technology can be successfully implemented in the financial sector, more specifically in financial institutions, and to assess whether it is indeed a tool with the potential to offer quality solutions to customers.

The main research objectives of this project are: to provide a theoretical framework on the evolution of the financial sector to identify when the use of blockchain technology began to gain prominence in the market, to understand the origin of blockchain and the fundamental concepts of its technology; to investigate institutional adoption, analyzing how various companies, governments, and other entities are using the technology; to understand how blockchain technology can be implemented in the banking sector; to address the importance of blockchain in defining the strategy of financial institutions; to analyze factors such as security and privacy; to assess consumer opinion regarding new services developed based on blockchain technology; and to identify the challenges inherent in implementing this technology.

To conduct this study, a theoretical framework (literature review) will be developed on the evolution of the financial sector, blockchain technology, its applicability in various sectors, and the barriers to its adoption. Following the review of the literature, a quantitative online survey will be conducted. The purpose of the poll is to learn how respondents feel about their likelihood of using blockchain-based services.

Participants' personal details, including age, gender, education, employment history, residence, and net monthly income, will be gathered as the first stage in the survey. The next set of questions ask about respondents' level of knowledge and opinion regarding new technologies, how often they use home banking and mobile applications to handle financial matters, how important certain factors are for handling financial matters, how well-versed they are in terms of blockchain, and how much customers accept financial institutions using blockchain to provide new customer services.

This study is structured into six main chapters. Next chapter presents the theoretical framework, reviewing literature on blockchain technology, its evolution in the financial sector, key theoretical concepts, applicability across industries, and its adoption in banking, including real-world cases and barriers to implementation. The third chapter details the research methodology, which follows a quantitative approach. The fourth chapter analyzes the data collected through an online survey, including sample characterization and the fifth chapter, econometric analysis of relevant variables and the discussion of results. The sixth chapter finally discusses the study's contributions and limitations, suggests areas for future research and presents the final conclusions.

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## 2. Literature Review

The rise of digitalization, the emergence of technology companies in the financial industry, and the advent of blockchain have prompted financial institutions to adapt their traditional business models to retain customers (Lopes, 2024). While several sectors generate more revenue from digital channels than traditional ones, banking has yet to follow this trend. Because consumers who are more likely to utilize digital channels are frequently younger and have less money to spend, the value of digital assets under control stays lower (Vilhena & Navas, 2023; Navas, Sotomayor & Darame, 2025).

DeFi, a subset of decentralized banking, offers an alternative to conventional systems by using blockchain technology and smart contracts for financial services including lending, trading, and insurance (Li et al., 2022). In



order to protect digital data from manipulation, Haber and Stornetta developed the idea of blockchain in the 1990s (Phartyal & Davi, 2022).

Lopes (2024) asserts that Distributed Ledger Technology (DLT), which provides a decentralized registry where data is held among numerous entities without a central administrator, signifies the start of the Crypto age. One kind of DLT is blockchain, which arranges digital data into interconnected blocks to create an ongoing chain (Ressi et al., 2024). Every computer connected to the network of nodes downloads and synchronizes with the most recent blockchain data (Gaikwad, 2020).

Blockchain blocks may store a variety of transaction information, including the date, time, amount, and participants, claims Gaikwad (2020). Because each block's hash value is connected to the one before it, cryptographic techniques make sure that changing a block's content would render the entire chain incorrect (Ressi et al., 2024). On the other hand, because the central node has complete authority, centralized networks are susceptible to power abuses (Lopes, 2024). Multiple nodes make up a decentralized blockchain, which is more resilient to assaults; even if some nodes are hacked, the network can continue to operate (Phartyal & Davi, 2022). One essential component that guarantees blockchain data cannot be changed without rendering the entire chain invalid is immutability (Tripathi, Ahad, & Casalino, 2023).

To join the network, nodes must adhere to a consensus procedure. While Proof of Stake chooses block makers based on the quantity of tokens owned, Proof of Work pits miners against one another to solve challenging puzzles and validate transactions (Gaikwad, 2020) (Lopes, 2024). In regulated private blockchains, the Proof of Authority process uses pre-selected validators (Islam, Merlec, & In, 2022).

Because private blockchains are centralized, they can process more transactions and reach consensus more quickly (Far & Asaar, 2024; Yang et al., 2020). Private blockchains are problematic because they lack a consensus method, but their performance and confidentiality are making them more popular in industries including banking, insurance, and logistics (Zhai, Shen, & Mao, 2024). Only authorized entities can access data in these systems (Zhai, Shen, & Mao, 2024).

Smart contracts are self-executing agreements built into computer programs that, when certain criteria are fulfilled, carry out actions automatically, doing away with the need for middlemen (Lopes, 2024; Hedge & Maddikunta, 2023). Their use of blockchain technology (Ante, 2021) offers a move toward programmable assets and more automated corporate transactions, increasing the likelihood of adoption (Ante, 2021).

But even with consumer protection measures in place, reliable profits are hampered by cryptocurrency volatility (Lopes, 2024). Because they are linked to fundamental assets like currencies or precious metals, which link them to the actual economy, stablecoins have become a viable alternative (Feng, Yuan, & Jiang, 2024; l'Etang, 2024).

Commercial banks are adopting digital currencies due to the shift away from cash, new technologies, and the growth of digitalization (Marszałek & Szarzec, 2021). However, this move to cashless transactions may worsen social inequality and financial exclusion, especially for households (Marszałek & Szarzec, 2021; Brandl, Hengsbach, & Moreno, 2024).

The invention of Bitcoin marked the first use of blockchain technology, as this research has already noted. However, as time has gone on, its use has spread beyond cryptocurrency to a variety of industries and commercial sectors due to increased interest and the perceived potential of more individuals (Casella et al., 2023). Beyond its significance in underdeveloped nations, blockchain technology is especially useful for remittance transfers, outperforming conventional techniques in terms of speed and accessibility at any time and to any location. According to Tripathi, Ahad, and Casalino (2023), this technology can provide value in a variety of industries. Blockchain is a useful tool for attaining sustainable supply chain management because of its special features, such traceability and transparency, which may help limit greenhouse gas emissions and the introduction of less sustainable items into supply networks (Duan, Pang, & Lin, 2024).



Online retail platforms are now able to communicate demand information with manufacturers, which in turn encourages them to enhance the quality of their products, thanks to the advancement of information technology and the availability of large volumes of customer data (Zhang, Zhu, & Ren, 2024). Artificial Intelligence (AI) has become a very helpful tool for more effectively handling complicated challenges. As AI continues to develop, some of the basic issues that blockchain systems encounter can be resolved thanks to its strengths in data analysis, pattern recognition, and automation (Lopes, 2024). The use of these two technologies is restricted to using blockchain as a distributed data storage solution and applying some degree of artificial intelligence to the data that is stored. In these cases, neither technology's full potential is being appropriately utilized for both parties' advantage (Ressi et al., 2024). The system's integrity is preserved by the significant decrease in transaction, administrative, and operational expenses as well as the guarantees of efficiency, security, real-time transaction speed, and quick document processing (Garg et al., 2021).

According to Deng (2020), long processing times, high prices, higher capital allocation, and inadequate security are the primary drawbacks of the conventional approach to cross-border transfers. First off, over 90% of cross-border transactions are related to the business-to-business (B2B) payment model, which contributes to the completion delays (Deng, 2020). It is crucial for institutions to implement robust controls and maintain an in-depth understanding of their customers and the transactions they conduct (Lopes, 2024). Financial organizations must thus make investments to enhance their Know Your Customer (KYC) procedures. All banks rely on the KYC procedure to confirm their customers' identities. To stop banks from being used for illicit purposes including money laundering, drug trafficking, financing terrorism, and other crimes, this verification is crucial. Patil and Sangeetha (2022) claim that manual KYC procedures are still the most common in use today. Nevertheless, it has several drawbacks, such as antiquated techniques, lengthier processing times, and security issues. Patil and Sangeetha (2022) support the notion that blockchain-based KYC verification can overcome the drawbacks of the manual approach since the technology offers important properties like security, immutability, and decentralization.

The retail banking sector in Portugal has experienced significant transformations, and the process has been further accelerated by the Covid-19 pandemic (Vilhena & Navas, 2023). The survey's findings, made in Portugal, indicate that, overall, respondents are content with the digital services provided by financial institutions. They perceive them as secure and exhibit a preference for Homebanking/Mobile Banking over traditional channels (Navas et al, 2025; Vilhena & Navas, 2023). Basdekidou and Papapanagos (2025) explore the intervening role in socioeconomic performance (SEP) of corporate environmental, cultural, and ethnic activities (ECEAs) and diversity, equity, inclusion, and social initiatives (DEISIs) on blockchain adoption strategy, particularly useful in the Western Balkans (WB), which demands transparency due to extended fraud and ethnic complexities. A serial mediation model was tested on a dataset of 630 WB and EU companies, and the research conceptual model was validated by CFA (Confirmation Factor Analysis), and the SEM (Structural Equation Model) fit was assessed. The authors confirmed the influence of technology, and environmental, cultural, ethnic, and social factors on blockchain adoption strategy and most of the hypotheses (21 out of 28) showed a strong correlation between the performance of sustainable entrepreneurship and the adoption of blockchain technology (Basdekidou and Papapanagos, 2025). Based on the findings, Basdekidou and Papapanagos (2025) concluded that the inclusion of green corporate activities and SEISIs initiatives, as mediating variables, strengthens the influence of blockchain adoption on SEP among firms operating in the multicultural and multi-ethnic areas.

Also, Sciarelli et al (2022) studies factors which affects the adoption of blockchain technology in innovative Italian companies (an extended TAM approach - Technology Acceptance Model) and results show that efficiency and security is an important driver of firms' decision-making process to adopt the technology. Moreover, the results show that perceived usefulness is a strong predictor of the intention to use blockchain in business processes (Sciarelli et al, 2022). Countries are studying the TAM for real applications across various services and sectors, such as blockchain adoption for authentication (Pham et al., 2025) and its use in combating corruption (Ayebofo et al., 2025). Even sectors like healthcare are already making plans and guidelines on the construction and application of medical blockchain (Chen et al., 2025).



The European Union (EU) has recognized the need for a digital finance strategy to address regulatory gaps and help relaunch and modernize the European economy in the aftermath of the COVID-19 pandemic (Pavlidis, 2021). Pavlidis (2021) claims that the EU legislative initiatives seek to unlock the potential of crypto assets while mitigating the risks to financial stability, market integrity and consumer protection and this will lead to additional and better financial products for consumers, improving financial inclusion and financing of businesses. But, according to Linden and Shirazi (2023), findings reveal that such regulation will most likely not accelerate the adoption of crypto assets in the EU financial services sector, at least not sufficiently or as intended and some suggestions are made to improve the proposal.

Another issue very present in blockchain are the “attackers” that have successfully launched assaults on cryptocurrency exchanges on various occasions in recent years, causing large financial losses estimated to be in the millions (Tripathi et al., 2023). Sybil attacks, which include the creation of several fictitious nodes inside the blockchain network to sway choices and alter network consensus, are another frequent instance of network compromise that compromises the security and operation of the network (Li, 2022). To fully utilize blockchain technology’s revolutionary potential while reducing the related legal and regulatory obstacles, governments, corporations, and regulators must work together effectively (Nembe et al., 2024).

Concluding the success of the adoption process, it is very important to avoid delays for companies and customers, current blockchains must increase their processing capacity; otherwise, the infrastructure of the sector would not be able to keep up with the increasing demand (Tripathi et al., 2023). Future trends rely on making it easier for people to switch from traditional to digital banking, technology is changing the financial environment. In addition, it is pushing economies in the direction of cashless transactions (Kour, 2023).

### **3. Methodology**

The next stage is to compare the findings of the questionnaire survey with the literature research after developing the theoretical framework of blockchain technology and assessing its applicability across different sectors. The goal is not only to comprehend how blockchain technology can be successfully applied in the banking industry, but also to determine whether clients believe in its potential and if it is an essential tool for providing them with high-quality solutions.

The questionnaire survey, which consists of a series of questions aimed at a group of respondents, often representative of a population, is a tool for gathering data thought pertinent to the topic being studied. Additionally, this methodology aims to verify theoretical hypotheses and analyze the correlations these hypotheses suggest (Quivy, Campenhoudt & Marquet, 2019). It is important to mention that, in this study, no data was used to calculate the sample’s representativeness.

To address the specific objectives outlined in the previous chapter, a questionnaire was conducted, consisting of three sections. The first section aims to provide a general characterization of the sample by including questions about the respondents’ sociodemographic profile. The second section of the questionnaire seeks to understand the respondents’ level of acceptance regarding new technologies. Finally, the third section aims to assess receptiveness to the digital transformation of the banking sector and the adoption of new products.

To facilitate the quantification of the data obtained, some questions were designed to allow short responses, with multiple-choice options (several choices) or binary answers (“Yes” or “No”). Additionally, the Likert scale was also used, where respondents are asked to indicate, on a numerical scale, their level of agreement or disagreement with the given statement (Joshi et al., 2015).

For data collection, an online survey was conducted using Google Forms platform. The survey was available from December 1, 2023, to February 1, 2024, through the following link: <https://forms.gle/u6wcj4CQnesPRX8C7>.

To facilitate the dissemination of the questionnaire, it was distributed via the Internet. Additionally, this method was chosen because the questionnaire addresses a topic related to the use of disruptive technology that operates exclusively through the Internet. For this reason, it makes sense that the sample is comfortable with using the



Internet, not only to understand its relationship with existing mobile applications provided by their banks but also to assess their level of acceptance of future blockchain-based proposals.

The survey was shared through Instagram and LinkedIn platforms. For this study, the target population included all Portuguese users of Instagram and LinkedIn, and a total of 168 valid responses were obtained. To validate the results of the questionnaire, a statistical analysis was conducted by calculating absolute and relative frequencies to obtain descriptive analyses of the results. Subsequently, cross-tabulations were performed between respondents' sociodemographic variables and certain relevant variables to test and draw conclusions about their relationships.

In this study, an objective analysis of the collected data is intended, which is why a scientific approach was chosen. The MS Data analysis software program was used for the analysis and processing of the information gathered from the questionnaire survey.

For each dependent variable (X1 to X11), a separate linear regression was estimated, with the sociodemographic variables (gender, age, educational qualifications, and monthly net income) as predictors. Gender was coded as 1 = female and 2 = male; age was treated as a continuous variable, while income is divided into several ranges (0–6 in ascending order), and academic qualifications were coded according to the respondents' highest level attained (0–7 in ascending order too; zero means other). Regarding independent variables, the Likert-type answers were direct (1–5 in ascending order), while the yes and no answers were treated as binary values (0 for no and 1 for yes).

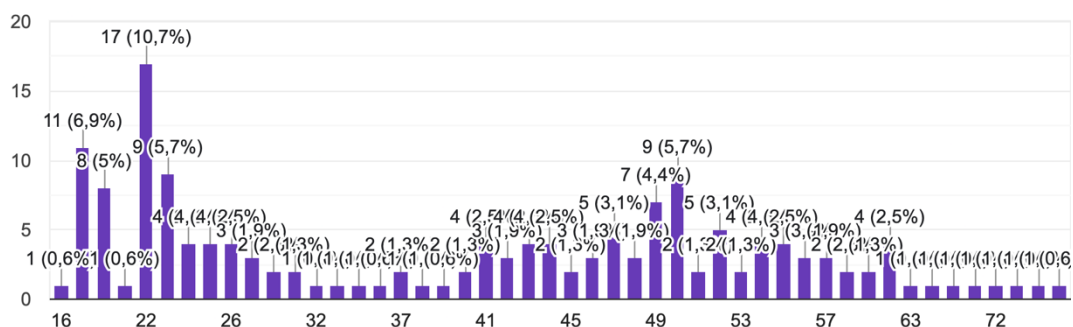
All models were estimated using the ordinary least squares (OLS) method, which the Excel tool implements by minimizing the sum of squared residuals. Models were run individually and then summarized in a single comparative table to facilitate interpretation. Only statistically significant predictors at the 1%, 5%, or 10% level were reported, while non-significant variables were tested and excluded but mentioned apart. The sample consisted of 168 valid responses, after excluding incomplete questionnaires. Although Excel offers fewer diagnostic options than specialized econometric software, it provides adequate outputs (coefficients, t-statistics, R<sup>2</sup>, significance levels) to support the exploratory nature of this research.

We are aware that Excel is a basic tool, with limited functionalities compared to specialized software (SPSS, Stata, R). However, it allows for the application of the OLS method sufficiently for the exploratory objectives of the study.

#### 4. Findings and Analysis

As shown in Figure 1, 56 respondents (34.6%) are under 25 years old, 14 respondents (8.8%) are between 26 and 35 years old, 24 respondents (15.1%) fall within the 36 to 45 age range, 44 respondents (27.7%) are between 46 and 55 years old, 16 respondents (10.1%) are between 56 and 65 years old, and only 6 respondents (3.8%) are over 65 years old. After analyzing the respondents' age groups, it is concluded that the majority are under 25 years old, while the least represented age group consists of respondents over 65 years old.

Figure 1: Distribution of ages of interviewees.





Of the 168 people who participated in the study, 99 are female and 69 are male. This means that the majority (58.9%) of the respondents are female, while 41.1% are male. Regarding the respondents' academic qualifications, 32.9% (n=55) have completed secondary education, 45.5% (n=76) hold a bachelor's degree, 11.4% (n=19) have obtained a master's degree, 5.4% (n=9) have completed a postgraduate degree, 0.6% (n=1) hold a PhD, 0.6% (n=1) have only completed basic education, and 1.8% (n=3) have other academic degrees. Around 71.4% (n=120) of the respondents are employees, 7.1% (n=12) are self-employed, 18.5% (n=31) are students, 2.4% (n=4) are retired, and 0.6% (n=1) are unemployed. Approximately 4.3% (n=7) earn less than €500, 11.6% (n=19) earn between €500 and €999, 26.2% (n=43) receive between €999 and €1,499, 15.2% (n=25) earn between €1,499 and €1,999, 14% (n=23) receive between €1,999 and €2,499, 14% (n=23) earn more than €2,500, and 14.6% (n=24) have no income. Regarding the respondents' level of knowledge about new technologies, the majority, 57.7% (n=97), stated that they have an intermediate level of knowledge. The minority, 1.2% (n=2), reported having no knowledge of new technologies, around 23.8% (n=40) indicated having basic knowledge, and 17.3% (n=29) claimed to have advanced knowledge. Table 1 provides a more detailed view of the descriptive statistics for the sociodemographic variables.

**Table 1:** Descriptive statistics for sociodemographic factors

Metrics	Gender	Age	Qualification	Income
Mean	1.4083	36.4438	3.503	3.1183
Standard Error	0.0379	1.3696	0.1114	0.1489
Median	1	40	4	3
Mode	1	22	4	3
Standard Deviation	0.493	17.8044	1.448	1.9359
Sample Variance	0.243	316.9983	2.0967	3.7478
Kurtosis	-1.8806	-0.7208	-0.4366	-0.9453
Skewness	0.3765	-0.0507	0	-0.2091
Range	1	77	7	6
Minimum	1	16	0	0
Maximum	2	77	7	6
Count	168	168	168	168
Confidence Level(95,0%)	0.0749	2.7038	0.2199	0.294

Regarding gender, the median and the mode of 1 both confirm that the majority of respondents are female, as the mean is over 1.5. The median age is forty, the mode is twenty-two, and the average is thirty-six. Given that the questionnaire was primarily distributed to the academic community, the mode of 22 indicates that the majority of respondents were younger. However, the median of 40, the wide range of 16 to 77, and the nearly symmetrical skewness (-0.05) suggest that the sample also contains a significant number of older participants. The majority of respondents have a bachelor's degree as their major, as shown by qualifications close to 4 (mean, median, and mode). According to the near three (mean, median, and mode) measures of income, the average respondent makes between €999 and €1499 (€14,000 and €21,000 a year). Details about classification attributed to various factors for the treatment of financial matters are detailed in Table 2, using a scale from 1 (not important) to 5 (very important).



**Table 2:** Classification of the treatment of financial matters.

Variable	Classification	Absolute Frequency	Relative Frequency
Personalized service	Not important	2	1.2%
	Slightly important	14	8.3%
	Indifferent	16	9.5%
	Important	81	48.2%
	Very important	55	32.7%
Efficiency	Not important	0	0.0%
	Slightly important	1	0.6%
	Indifferent	2	1.2%
	Important	43	25.6%
	Very important	122	72.6%
Ease of use of digital platforms	Not important	0	0.0%
	Slightly important	0	0.0%
	Indifferent	6	3.6%
	Important	61	36.3%
	Very important	101	60.1%
Speed	Not important	0	0.0%
	Slightly important	2	1.2%
	Indifferent	0	0.0%
	Important	53	31.5%
	Very important	113	67.3%
Fees and costs	Not important	0	0.0%
	Slightly important	6	3.6%
	Indifferent	15	8.9%
	Important	36	21.4%
	Very important	111	66.1%
Reputation of the financial institution	Not important	0	0.0%
	Slightly important	2	1.2%
	Indifferent	15	8.9%
	Important	58	34.5%
	Very important	93	55.4%
Proximity to the financial institution	Not important	1	0.6%
	Slightly important	11	6.5%
	Indifferent	51	30.4%
	Important	54	32.1%
	Very important	51	30.4%
Security	Not important	0	0.0%
	Slightly important	1	0.6%
	Indifferent	0	0.0%
	Important	17	10.1%
	Very important	150	89.3%

Regarding the respondents' level of confidence in making payments over the internet, only 2.4% (n=4) rated their confidence level as very low, while 4.2% (n=7) rated it as low. Additionally, 19.6% (n=33) classified their confidence level as neutral, 53.6% (n=90) rated it as high, and finally, 20.2% (n=34) reported having a very high level of confidence in making online payments. It is observed that 98.2% of respondents (n=164) consider the



use of mobile applications a valuable tool for managing financial matters. In contrast, 1.8% of respondents (n=3) hold an opposing view and do not believe in their usefulness for facilitating financial management. It is also observed that 91.1% of respondents (n=153) use a mobile application to manage financial matters related to their bank account. On the other hand, 8.9% (n=15) do not use any mobile application for such purposes. Regarding the main reasons why respondents do not use homebanking, approximately 35.3% (n=6) stated that they do not use this functionality due to security concerns, 35.3% (n=6) do not use it because they do not have a bank account, 5.9% (n=1) mentioned lack of knowledge as the reason, and 23.5% (n=4) cited other reasons. Regarding respondents' preferred payment methods for making payments or transfers, approximately 41.3% (n=69) prefer using ATMs, 31.7% (n=53) favor mobile applications, 23.4% (n=39) use Homebanking, and 3.6% (n=6) prefer cash (coins and banknotes). It can be concluded that most respondents prefer using ATMs for payments. On the other hand, it is evident that cash payments have been increasingly less utilized, with only 3.6% of the sample favoring this method.

It is possible to draw some conclusions regarding respondents' knowledge of certain blockchain-related topics. Out of 168 responses, 7.5% (n=12) of respondents are familiar with the term DLT, 46.9% (n=75) recognize the term Blockchain, 91.9% (n=147) are familiar with the concept of cryptocurrencies, 28.1% (n=45) understand the term smart contracts, 27.5% (n=44) comprehend the concept of Fintechs, 6.9% (n=11) are aware of the term DeFi, 20% (n=32) understand the concept of asset tokenization, and 18.8% (n=30) are familiar with the term Stable Coins. It can be concluded that blockchain technology and the concept of cryptocurrencies are the most well-known topics among respondents.

One of the survey's questions sought to gauge respondents' thoughts on the prospect of the banking industry becoming entirely digital in the future, doing away with the necessity for physical branches. About 31% of respondents (n=52) think this situation is feasible, whilst 69% of respondents (n=116) do not think it is possible.

It is possible to observe respondents' opinions on the use of an application developed by their own bank to monitor cryptocurrency market activity, alerting them to good buying or selling opportunities. Around 56.9% of respondents (n=95) expressed interest in this new service from their bank and stated that they would use it. However, 43.1% of respondents (n=72) are still not comfortable investing in this market and stated that they would not use such an application.

Regarding respondents' opinions on acquiring cryptocurrencies if their bank offered its own cryptocurrencies or assisted them in incorporating them into their portfolio, 63.1% of respondents (n=106) responded positively to this possibility. In contrast, 36.9% of respondents (n=62) stated that even with their bank's support, they would still not consider the proposal advantageous.

When asked about the possibility of using a cryptocurrency developed by their bank to significantly improve the efficiency, speed, and security of transfers, 68.5% of respondents (n=115) considered it a good initiative. However, 31.5% of respondents (n=53) stated that they would not use a cryptocurrency developed by their bank, even if it substantially enhanced transaction efficiency.

The objective is to understand whether respondents who previously answered negatively believe their opinion might change in 10 years. When faced with this temporal perspective, 71.7% of respondents (n=43) acknowledged the possibility of reconsidering and using a cryptocurrency developed by their bank to enhance transaction efficiency in the future. However, 28.3% of respondents (n=17) maintained a firm stance on this topic, believing that their opinion will remain unchanged over the next decade.

Regarding the perceived security of blockchain-based financial products, if banks were to take a more active and intelligent role in managing their clients' portfolios, 66.5% of respondents (n=107) stated that they would feel more confident in the process. However, 33.5% of respondents (n=54) indicated that the bank's involvement would not change their stance, and they would still prefer not to make such investments.



Regarding the potential adoption of a bank-developed application aimed at improving the speed of international transfers at no additional cost, 92.1% of respondents (n=152) stated they would be willing to use it, while only 7.9% (n=13) expressed disinterest in this solution.

The final question of the survey aimed at assessing respondents' opinions on whether they would consider switching to a competitor if their bank did not offer the previously mentioned services. The results show that approximately 67.3% of respondents (n=111) indicated that they would switch banks under these circumstances. On the other hand, 32.7% (n=54) stated that this factor would not influence their relationship with their current bank and would not prompt them to seek alternatives.

To have a better understanding of these variables, table 3 presents the descriptive statistics for classification of the treatment of financial matters. Security emerges as the most valued attribute (mean = 4.89, 89% "very important"), followed by efficiency and speed (means around 4.7). In contrast, proximity to the financial institution was the least valued factor, with a mean below 4. This pattern highlights the strong customer preference for digital convenience and reliability over physical presence.

**Table 3:** Descriptive statistics for classification of the treatment of financial matters

Variable	Mean	Median	Mode	Std. Dev.	N
Personalized service	4.03	4	4	0.85	168
Efficiency	4.70	5	5	0.55	168
Ease of use of digital platforms	4.57	5	5	0.61	168
Speed	4.66	5	5	0.58	168
Fees and costs	4.50	5	5	0.70	168
Reputation	4.44	5	5	0.72	168
Proximity	3.85	4	4	0.94	168
Security	4.89	5	5	0.35	168

## 5. Discussion

In this chapter, an analysis of the variables will be conducted to examine their relationships and understand how the sociodemographic variables of the questionnaire (gender, age, educational qualifications, and monthly net income) influence the respondents' answers to the remaining questions. Table 4 is derived from the linear regression performed in MS Data Analysis based on the questionnaire survey responses. Only statistically significant variables for the model will be presented, while non-significant variables will not be included. The Regression analysis tool performs linear regression analysis by using the "least squares" method to fit a line through a set of observations.



Table 4: Linear regression analysis.

Dependent variable	R2	Intercept		Gender		Age		Academic qualifications		Monthly net income	
		Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
X1 **	0.06	2.70 ***	12.49	0.22 **	2.07	-0.01 **	-1.99	0.02	0.65	0.02	0.68
X2 ***	0.15	0.96 ***	20.63	-0.04	1.56	0.01 ***	4.59	0.02 ***	2.73	-0.03 ***	-4.05
X3 **	0.07	1.49 ***	3.25	-0.09	0.44	-0.08	1.10	-0.08	-1.10	-0.12 *	-1.77
X4 ***	0.13	2.34 ***	8.65	-0.30 **	2.33	0.01	1.64	0.08 *	1.71	0.08 **	1.98
X5 ***	0.08	4.95 ***	16.76	-0.30 **	2.13	0.01	0.29	-0.12 **	-2.37	-0.03	-0.77
X6 **	0.07	4.96 ***	27.60	-0.05	0.67	0.01 ***	2.71	0.01	0.07	-0.01	-0.40
X7 *	0.05	4.95 ***	27.98	-0.07	0.77	0.01 **	2.56	0.01	0.22	0.01	0.39
X8 **	0.06	4.28 ***	16.58	-0.16	1.33	-0.01	0.29	0.09 **	2.14	0.05	1.25
X9 **	0.06	5.04 ***	22.27	-0.08	0.74	0.01 **	2.28	-0.10 ***	-2.73	0.06 *	1.74
X10 *	0.05	0.57 ***	3.18	0.15 **	2.06	-0.01	0.52	-0.05 *	-1.89	0.01	0.56
X11 *	0.05	1.04 ***	9.57	-0.02	0.62	0.01 **	2.48	-0.01	-1.15	0.03 **	2.43

Number of observations: 168

Notes:

X1 — Level of knowledge regarding new technologies

X2 — Respondents’ perception of the usefulness of mobile banking applications to facilitate the handling of financial matters

X3 — Reason for not using homebanking

X4 — Preferred payment method for making payments or transfers

X5 — Ranking the importance of personalized service for dealing with financial matters

X6 — Ranking the importance of ease of use of digital platforms for dealing with financial matters

X7 — Ranking the importance of speed in dealing with financial matters

X8 — Ranking the importance of fees and costs for dealing with financial matters

X9 — Ranking of the importance of the reputation of financial institutions in dealing with financial matters

X10 — Acceptability of acquiring cryptocurrencies if the bank offers its own cryptocurrencies, or helps its customers to have them in their portfolio



X11 — Acceptability of using a mobile application created by the bank to improve efficiency, speed, and security in transfers, facilitating cross-border transfers and currency conversion.

\* — Statistical significance at 10%; \*\* — Statistical significance at 5%; \*\*\* — Statistical significance at 1%

Coef. = Coefficient

Gender signals: 1 — feminine; 2 — masculine

Table 4 presents the results of a multiple linear regression analysis with 168 observations, assessing the impact of sociodemographic variables (gender, age, academic qualifications, and monthly net income) on different dependent variables related to financial technology and banking perceptions. The explanatory power of the models varies, with the highest  $R^2$  value (0.15) observed for X2, which represents the perceived usefulness of mobile banking applications. Other models exhibit relatively low  $R^2$  values, suggesting weak explanatory power. However, statistically significant variables still provide valuable insights.

The intercepts for all dependent variables are statistically significant at the 1% level, indicating that even in the absence of the independent variables, there is a baseline level of response for each dependent variable. Regarding gender, males report higher levels of knowledge about new technologies (X1), as evidenced by a positive and significant coefficient (0.22,  $p < 5\%$ ). On the other hand, gender has a negative impact on the significance of customized banking services (X5) (-0.30,  $p < 5\%$ ) and the chosen payment method (X4) (-0.30,  $p < 5\%$ ), suggesting that men are less inclined to value personalized service and favor certain payment methods. Additionally, gender has a positive and significant effect (0.15,  $p < 5\%$ ) on the acceptability of cryptocurrencies given by banks (X10), indicating that men are more willing to purchase cryptocurrencies through banks.

The amount of knowledge about new technologies is negatively impacted by age (X1) (-0.01,  $p < 5\%$ ), indicating that older respondents had lower levels of expertise. In a similar vein, older respondents place somewhat less weight on financial institution reputation (X9) (-0.01,  $p < 5\%$ ) and transaction speed (X7) (-0.01,  $p < 5\%$ ). Furthermore, older individuals show less acceptance of mobile banking applications for transfers (X11) (-0.01,  $p < 5\%$ ). However, age positively affects the perceived usefulness of mobile banking applications (X2) (0.01,  $p < 1\%$ ), suggesting that older respondents recognize their utility.

Academic qualifications play a significant role in several aspects. Higher academic qualifications lead to greater perceived usefulness of mobile banking applications (X2) (0.02,  $p < 1\%$ ). Education level also influences the preferred payment method (X4) (0.08,  $p < 10\%$ ) and the importance of fees and costs (X8) (0.09,  $p < 5\%$ ). However, higher education levels decrease the perceived importance of personalized banking services (X5) (-0.12,  $p < 5\%$ ) and slightly reduce the acceptance of cryptocurrencies via banks (X10) (-0.05,  $p < 10\%$ ).

Monthly net income is also a determining factor. Higher income is associated with a lower perceived usefulness of mobile banking applications (X2) (-0.03,  $p < 1\%$ ), suggesting that wealthier individuals may already have alternative financial management solutions. However, these individuals attribute greater importance to the reputation of financial institutions (X9) (0.06,  $p < 10\%$ ) and show greater acceptability of mobile banking applications for transfers (X11) (0.03,  $p < 5\%$ ). Higher-income respondents are also less likely to cite reasons for avoiding home banking (X3) (-0.12,  $p < 10\%$ ) and place less value on personalized banking services (X5) (-0.03, not significant).

In conclusion, the data shows clear trends in banking choices and the use of financial technology according to sociodemographic characteristics. Elderly respondents found mobile banking apps more helpful, although younger and male respondents are more tech-savvy. Larger income respondents place a larger value on financial institution reputation and are more receptive to mobile banking apps, whereas more education is associated



with a greater emphasis on fees and expenses. Furthermore, there are differences in bitcoin adoption by education and gender, with more educated respondents exhibiting a little amount of hesitancy and men exhibiting higher openness. These findings provide insights into how different demographics engage with digital banking services and financial technology, highlighting potential areas for tailored strategies in the financial sector.

To assess potential heteroscedasticity, we regressed the squared residuals on the set of sociodemographic variables used in the original specification (Breusch–Pagan type procedure). The regression revealed a non-significant F-test ( $p > 0.05$ ) and limited explanatory power ( $R^2 < 0.05$ ), indicating that heteroscedasticity is not an issue in our model. Nonetheless, there were indications of heteroscedasticity ( $p < 0.05$ ) for two variables, X6 and X9. The gender variable's binary design, which divides the sample into two subgroups (male and female) and might highlight differences in residual variance between groups, may be to blame for this result. In practice, this outcome indicates that the dispersion of responses for these constructs differs slightly between men and women, even though the overall explanatory power of the models remains weak. To ensure robustness, we verified that the use of heteroscedasticity-consistent (HC) standard errors did not materially affect the significance or direction of the coefficients.

The excluded variables were: 1) Using a mobile application to handle bank account-related matters, 2) Degree of trust when making payments online, 3) Importance of efficiency in dealing with financial matters, 4) Importance of proximity to the financial institution when dealing with financial matters, 5) Importance of security when dealing with financial matters; 6) Opinion on the possibility of a future of exclusively digital banking, completely dispensing with the presence of physical branches, 7) Opinion on the use of an automated software application developed by the bank to monitor cryptocurrency activity, alerting customers of good buying or selling opportunities, 8) Opinion on the use of a cryptocurrency developed by the bank, if this would ensure a significant improvement in the efficiency, speed and security of transfers, 9) Opinion on trust when marketing products developed on blockchain technology, if the bank had more active and intelligent management of its customers' portfolios, and 10) Opinion on a possible move to the competition if the bank does not offer a mobile application with the intention of improving efficiency, speed and security in transfers, facilitating cross-border transfers and conversion between different currencies.

The exclusion of these variables from the final model suggests that they did not show statistically significant relationships with the dependent variables under analysis. Their omission does not, however, imply that they are not pertinent to a larger conversation about financial behavior and developments in digital banking. The impact of user behavior in mobile banking is one possible consideration with reference to the omitted factors. The exclusion of utilizing a mobile application for bank account-related tasks may suggest that respondents' opinions of financial digitalization are not greatly impacted by their overall usage of these apps. This may indicate that mobile banking is already widely used and is not a significant factor in explaining response variances. Furthermore, it is significant that the level of confidence in online payments and the significance of security in handling financial concerns are not included. Their removal may imply that other variables, such as age, income, or the overall image of digital banking, better capture these issues, which are frequently mentioned as major difficulties for digital financial transactions.

Additionally, the lack of statistical significance for the significance of proximity to the financial institution and efficiency in handling financial matters may suggest that these factors are already deemed important by most respondents or that their influence is lessened by other, more readily measurable factors. Similarly, the fact that the perspective on the prospect of a future with just digital banking was left out indicates that respondents' opinions on the demise of physical branches had no bearing on their financial activity or preferences for online banking. Additionally, several characteristics that are not included pertain to cryptocurrencies and blockchain technology, such as the desire to embrace a cryptocurrency issued by the bank, the usage of an automated cryptocurrency monitoring system, and faith in blockchain-based goods. Their absence could suggest that

respondents still find certain subjects too specialized or divisive, which could result in irregular or non-statistically significant trends.

Finally, the lack of statistical significance in the respondents' view on a potential shift to a competitor bank if the bank does not have a mobile application may indicate that respondents are not always motivated to change banks based just on the availability of mobile apps. Retention may be more strongly influenced by other elements including reputation, trust, and customer service. Overall, these factors are still pertinent for qualitative conversations on customer behavior and developments in digital banking, even though they were eliminated for statistical reasons. Future studies might examine if their effects alter depending on a person's financial situation or demographic group.

The research question guiding this study concerns how blockchain technology can be successfully implemented in financial institutions and whether it has the potential to provide quality solutions to customers. Customers place the highest value on security, efficiency, cheap costs, ease of use of digital platforms, and financial institutions' reputation, according to Table 2's descriptive data. These goals are quite similar to the main characteristics of blockchain technology, which include transparent and safe transaction records, lower costs due to disintermediation, and more effective payments and transfers. Therefore, it appears from the data that blockchain-based solutions immediately address the factors that consumers find most important when interacting with financial institutions.

Table 4 presents a regression analysis which contributes to the research topic by identifying the sociodemographic groups that are most likely to adopt blockchain-related innovations. The results indicate that consumers' inclination to use digital financial solutions, like cryptocurrencies and mobile apps supported by banks, is influenced by a few factors, including age, income, and educational qualification. Younger responders and those with higher incomes are especially receptive to innovations, whereas other categories exhibit more conservative viewpoints. These results show that blockchain may provide clients with high-quality solutions, but in order to enhance acceptability and confidence, its implementation plan should take demographic variation into account.

When combined, the descriptive and regression studies show that financial services can successfully incorporate blockchain technology. Financial institutions may create technically sound and socially responsive blockchain-based products by addressing the different levels of openness across demographic groups and aligning with consumers' key interests. This supports the claim that blockchain is a tool that has the potential to significantly enhance customer satisfaction and service quality in addition to being a technological advancement.

## 6. Conclusion

In addition to addressing the financial sector's progress, this research sought to give a broad overview of the main theoretical ideas behind blockchain technology. The study also aimed to determine whether clients of financial institutions would be willing to employ services based on this technology by means of a questionnaire survey. The current study provides a thorough examination of the ways in which sociodemographic factors—such as age, gender, educational attainment, and monthly net income—affect people's understanding and usage of modern financial technology. The study advances knowledge of technology adoption trends across various demographic groups by elaborating on these linkages.

Although previous studies have mostly focused on the technical capabilities of blockchain systems, our results show that consumer perceptions of security, effectiveness, and trust are just as important to the success of blockchain adoption in financial institutions. This study also adds to the existing literature the acceptance of the technology by showing that demographic factors affect the willingness to adopt blockchain-based services and highlights the necessity of incorporating demographic heterogeneity into frameworks like the Unified Theory of Acceptance and Use of Technology (UTAUT) and TAM.



The study confirms the existing literature that link demographic factors to financial behaviors and usages, using linear regressions, and it may be used as a basis for further research, offering a strong framework for examining comparable data in many circumstances. More in-depth research on technological innovation in the financial industry and its obstacles may be possible if important determinants for the adoption and usage of financial technology, such as cryptocurrencies and mobile banking apps, are identified. The results, which show notable variations in financial technology usage and expertise by age and gender, might influence digital education programs and public policy. Knowing which groups need additional assistance and education can help drive the promotion of digital inclusion more successfully.

From a managerial perspective, the results provide insights for financial institutions planning to integrate blockchain into their services. When creating blockchain-based solutions, banks should give top priority to the aspects that clients appreciate most like security, efficiency, and cost reduction. In order to engage certain client segments, especially older users or those with lower levels of digital literacy — who could be more hesitant to embrace disruptive technology — it can also be required to employ specialized communication tactics. The findings highlight how crucial it is for regulators and legislators to ensure that blockchain regulation promotes digital inclusion while also fostering trust, openness, consumer protection and security.

Financial institutions could offer more inclusive products and services by recognizing that different demographic groups use and acceptance of the technology to differing degrees. For example, advertising can be designed to inform and draw in older people if younger people are more likely to adopt new technology. They also can use data on behaviors, preferences on payment methods and personalized customer service to enhance their marketing strategies. By segmenting their audience based on demographic and behavioral data, institutions can increase customer satisfaction and encourage them to adopt new products and services. Determining the factors that affect the adoption of new financial technology might help different populations become more financially empowered. Workshops and targeted training programs may be created to improve financial literacy and boost self-assurance while utilizing digital tools for money management.

This study's information was gathered from online sources, which is one of its limitations. This suggests that some banks might be further along in their blockchain implementation but were overlooked because they did not have access to the information. An additional constraint pertains to the sample that was employed in the questionnaire survey. The results cannot be extended to the entire population since the survey was distributed online, and a convenience sample was used for the study. Furthermore, the results might not be as representative of the variety of views and practices present in other groups because the majority of respondents are Portuguese.

Obtaining a more representative sample of responders that includes more individuals from other nations and locations is one recommendation for future study. A thorough investigation of the application of blockchain technology in corporate banking (commercial banks and investment banking) would also be pertinent, given that the technique employed in this study was centered on comprehending the viewpoints of retail banking clients. The aim would be to understand the perspectives of business owners regarding the adoption of this technology by financial institutions.

Based on the conducted study, it is concluded that, in general, respondents consider online banking services to be secure. Most of the respondents state that home banking is an effective tool for managing financial matters, and it is their preferred method for making payments or transfers. Regarding the most valued factors when dealing with financial matters, security emerged as the most consensual aspect among respondents, being considered the most important feature by all participants, who rated it as extremely important. Blockchain and cryptocurrencies stand out as the terms most familiar to respondents. On the creation of a bank-owned app to track cryptocurrency market activity and alert clients to favorable buying or selling opportunities, there were differing views. Even though over 50% of the participants thought this project was feasible, others expressed little interest in the idea of using it to make bitcoin investing easier. Similar patterns were seen in the purchase



of cryptocurrencies to improve transfer efficiency—while a small minority showed no interest, a sizable portion thought their views may shift over the course of the following decade.

When asked if they would have more faith in blockchain-based financial products if banks took a more proactive and astute approach to portfolio management, the majority of respondents gave a favorable response. Regarding the potential adoption of a bank-developed application to improve the speed of international transfers at no additional cost, the overwhelming majority indicated they would use it. Furthermore, when questioned about the possibility of competitors offering such services, many respondents stated they would consider opening an account with a competing institution or even switching banks entirely if their current bank did not provide these services. Security and the use of an application to speed up transfers are essential and highly regarded characteristics among respondents when handling financial problems, based on the positive answers about the adoption of blockchain technology by financial institutions. These revelations demonstrate this revolutionary technology's enormous potential.

It is encouraged that banks keep a careful eye on these developments and organize creative blockchain implementation projects to speed up KYC procedures, ease transfers, develop smart contracts, and investigate other uses. These advancements are required to keep rival financial institutions from outperforming them and to offer value-added services that preserve client loyalty and confidence. By using blockchain technology, financial institutions can increase their competitiveness and guarantee the ongoing satisfaction and trust of their clients.

This study also shows that blockchain has an excellent opportunity to improve the quality of services in the financial industry, but its success hinges on matching technology to client needs and modifying implementation tactics to suit a range of demographics. These ramifications broaden the scholarly discourse on blockchain adoption as well as the realistic implementation roadmap for financial institutions.

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### Ethical Statement

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Participation in the survey was entirely voluntary and at the first page all participants were informed about the purpose of the study, the estimated time required to complete the survey, and their freedom to stop participating at any time without facing any consequences, providing online consent since participants could only finish the questionnaire after confirming their agreement. No personally identifiable information was collected, and responses are entirely anonymous. Data was securely stored and used exclusively for academic purposes, for a master dissertation and the current paper. No additional ethical approval was required in accordance with institutional standards since the survey was non-invasive and did not cover any sensitive subjects.



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# Entrepreneurial innovation through quality function deployment: From customer voice to measurable design in a ready-to-eat taro product

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## Abstract

This article couples a critical review of QFD in food engineering with a hands-on House of Quality for a ready-to-eat (RTE) taro product. We translate the Voice of the Customer (VoC) into auditable, process-controllable HOWs—including pH limits, shelf-life targets, validated allergen control, sensory thresholds, and quantified sustainability indicators (packaging oxygen transmission rate [OTR], water vapor transmission rate [WVTR], % recycled content, supplier certification criteria). Using exploratory consumer data ( $n = 24$ ) and expert judgment, we compute importance weights and roof correlations that surface key trade-offs among safety, texture, convenience, and clean-label positioning. The result is an ISO 16355-aligned blueprint that connects consumer value to engineering decisions and supplier QA, suitable for Stage-Gate governance. While the sample is modest and generalization is limited, the template is replicable and raises the bar for operationalizing “sustainability” and “quality” beyond declarative claims. We discussed limitations and provide a checklist to adapt the HoQ to other RTE products. Further, by tying VoC to measurable targets and gate reviews, the blueprint supports opportunity validation and de-risked commercialization pathways for entrepreneurial food ventures.

**Keywords:** House of Quality; ISO 16355; Oxygen Transmission Rate; Quality Function Deployment; Ready-to-Eat.

## 1. Introduction

Today’s food industry increasingly demands the continuous development of innovative products. (Costa et al., 2000) The future success of any food company depends upon the effective use of the New Product Development (NPD) process. (Stewart-Knox & Mitchell, 2003) A wide range of product development process factors influence product success and failure. (Stewart-Knox, & Mitchell, 2003) Such key factors for food product development are market and consumer knowledge and retailer involvement. (Stewart-Knox & Mitchell, 2003) Developing products that meet consumer expectations require careful and systematic research. (Pop et al., 2020) The European agri-food sector invests significantly less in research and development compared to other industries and tends to adopt a conservative stance on the innovations it introduces. Truly innovative products are quite rare, making up only 2.2% of all product launches. In contrast, around 77% of launches consist of variants or improvements of existing products. (Costa et al., 2006) To understand this conservative consumer’s behaviour is important to understand the food neophobia phenomena. The terminology of food neophobia is derived from the concept introduced by Rozin and Vollmecke about the “*Omnivore’s dilemma*”, which explains the tendency to select familiar and safe foods rather than novel and unfamiliar ones. (Siddiqui, S. A. et al., 2022) NPD is often recommended as an effective strategy to achieve competitive advantage and long-term financial success in today’s global food industry. (Costa et al., 2006) Consumer needs should be the primary focus of NPD. The NPD process must aim to satisfy these needs rather than solely emphasizing the development of enabling products or technologies. The success of an NPD process should be measured by how well the new product aligns with consumer needs. (Costa et al., 2006) In order to survive in the market, companies must produce exactly the product the consumer has been waiting for now the consumer wants it. (Benner et al., 2003) QFD is a planning process for the design of new products. (Bech et al., 1997) However, despite increasing calls for consumer-oriented innovation, few complete and published applications for Quality Function Deployment (QFD). Most



studies remain theoretical or restricted to the initial stages of the methodology, which leaves a clear gap in understanding how QFD can be effectively adapted to food product development.

In recent years, several studies have reinforced the relevance of QFD for innovation in the food and packaging industries. Recent applications have linked QFD with digital transformation, sustainability, and hybrid design methodologies (Santoso et al., 2024; Mudgal et al., 2024; Peres et al., 2025). These developments are discussed in more detail in Section 1.1.2, which reviews the most recent advances and emerging directions of QFD research in the food sector. This study presents a valuable contribution to the field of food product development by providing a practical case study that corroborates the effectiveness of the QFD methodology. This practical case study not only contributes to existing literature but also provides actionable insights for industry professionals seeking to apply QFD in their own product development efforts. While many studies discuss the theoretical aspects of QFD, this study stands out by showcasing its real-world application in the creation of a new functional food product: a ready-to-eat taro (*Colocasia esculenta*). This study goes beyond theoretical discussions by providing a concrete example of how QFD can be applied in the food industry to develop a new product. By combining a literature review with a practical case study, it bridges theory and practice, demonstrating how consumer insights can be systematically translated into product attributes. In doing so, it offers a structured framework for companies—particularly small and medium enterprises—to optimize their innovation and product development processes. Ultimately, the study highlights QFD as a practical and effective methodology for achieving success in new food product development. By integrating QFD with entrepreneurial innovation logic, this study positions methodological rigor as a lever for sustainable business creation and food system transformation.

### **1.1. Quality Function Deployment**

To provide a clearer understanding of the methodology applied in this study, this section outlines the foundations of QFD, its origins, principles, and relevance to food product development. QFD is a well-structured inter-functional planning technique, a methodology for continuous product improvement, focusing on multifunctional teams to integrate the voice of customer (VoC) in the stages of planning, (Pop et al., 2020) QFD is an overall concept that provides a means of translating customer requirements into the appropriate technical requirements. (Chan and Wu, 2002) QFD facilitates the product development process, ensuring that customer requirements are considered throughout the technological process, and then reflecting in the final product. It takes a large effort and a lot of time to conduct QFD for the first time. However, once it has been executed it will speed up the time-to-market and enable the company to improve the product at less cost. (Benner et al., 2003) The QFD methodology, while widely used in industries such as automotive, remains underutilized in the food sector. This is due to both the complexity of the methodology and the lack of a structured approach that efficiently integrates consumer requirements into the final product's properties. QFD, was originally developed in Japan in the 1970s for the automobile industry. According to Hofmeister (1991) the QFD methodology has been used in the food industry since 1987. (Benner et al., 2003) Subsequent studies confirmed that QFD can support the systematic design of food products (Viaene & Januszewska, 1999).

Two significant benefits have been identified when introducing QFD. First, a well-defined conceptual research phase can substantially reduce production costs. Second, through consumer segmentation and analysis, companies can increase potential market share when launching a new product (Viaene & Januszewska, 1999). In this context, QFD serves as a valuable tool to optimize the new product development process, ensuring that consumer expectations are addressed from concept to commercialization. The first documented QFD case study in the United States was in 1986, when Kelsey Hayes used the methodology to develop a coolant sensor (Chan & Wu, 2002). Early adopters included major companies such as 3M, AT&T, Baxter Healthcare, Budd, Chrysler, DEC, Ford Motor, General Motors, Goodyear, Hewlett-Packard, IBM, ITT, Kodak, Motorola, and NASA (Chan & Wu, 2002). Many other organizations have since applied QFD and reported substantial benefits, and its use continues to expand across various sectors.

While QFD has achieved widespread success in engineering and manufacturing, its potential within the food industry remains underexplored. This justifies its adaptation in the present study, which applies QFD to the development of a ready-to-eat taro product.

### **1.1.1. ISO 16355-1:2021**

ISO 16355-1:2021 (*Application of statistical and related methods to new technology and product development process*), promotes a systematic approach to support decision-making in product innovation (ISO, 2021). Within the context of QFD, ISO 16355-1:2021 is highly relevant because it formalizes many of the practices that QFD practitioners have applied since the methodology was first developed (Akao & Mazur, 2020). The standard encourages a systematic approach, integrating customer-driven data with statistical analysis to reduce uncertainty in new product development.

For the food industry, this standard represents an opportunity to increase methodological rigor in the adoption of QFD. It provides clear directions on how to structure customer requirements, define measurable target values, and evaluate risks. Although ISO 16355 has been mostly applied in engineering and manufacturing contexts, its principles can be adapted to food product development, where consumer preferences and sensory attributes play a decisive role (Jugulum & Samuel, 2021). In this sense, ISO 16355-1:2021 complements the QFD methodology by aligning it with international best practices for product innovation.

### **1.1.2. Recent Developments in QFD for the Food Industry**

Recent literature has connected QFD with the emerging paradigm of Quality 4.0, which combines traditional quality management with digital technologies and data-driven decision-making. Santoso et al. (2024) emphasized QFD as a key tool in this context, showing how it structures innovation processes that were previously intuitive, while Peres et al. (2025) demonstrated how digital quality systems in the food industry can integrate QFD within smart manufacturing and continuous improvement frameworks.

Beyond digitalization, several studies have explored hybrid and sustainability-oriented approaches. Tri Ummarta et al. (2024) combined QFD with fuzzy logic to support the development of coffee-based products, and Ishak et al. (2024) integrated QFD with axiomatic design in the valorization of soybean milling by products. Similarly, Mudgal et al. (2024) applied a QFD Kano model to sustainable packaging design, and Wirawan et al. (2024) used QFD to enhance packaging convenience and usability. Siwiec et al. (2025) further expanded the methodology by coupling QFD with Life Cycle Assessment (LCA) to connect quality planning with environmental impact analysis, while Wicaksono et al. (2025) applied QFD principles to cleaner-production strategies in food-service operations.

These recent contributions confirm that QFD is becoming increasingly integrated with data-driven, hybrid, and sustainability-focused frameworks, aligning with contemporary trends in food innovation and circular-economy practices. From healthier formulations to waste-reduction strategies, the methodology is proving adaptable to both consumer expectations and sustainability goals. This growing body of evidence supports the idea that QFD is moving beyond theory and establishing itself as a practical, cross-disciplinary tool for entrepreneurs and food companies (Fagnoli & De Minicis, 2023; Santoso et al., 2024; Peres et al., 2025; Wicaksono et al., 2025).

## **1.2. QFD Limitations**

Although QFD has shown considerable potential across industries, several limitations have been highlighted in the literature, particularly when applied to the food sector. Recognizing these constraints is essential to understanding both the challenges and opportunities for its adaptation. One of the most frequently mentioned issues is the incomplete application of the methodology. Most studies on QFD in the food sector stop at the HoQ, and few complete applications have been published (Benner et al., 2003; Cohen, 1995). Another limitation is the scarcity of case studies. Companies are often reluctant to share detailed experiences for competitive reasons, which makes empirical validation difficult and leaves researchers with only partial accounts (Benner et al., 2003).

These limitations explain why QFD remains underutilized in the food sector. However, they also highlight the importance of further practical applications. By adapting the methodology to food-specific requirements, it is

possible to demonstrate its potential and provide entrepreneurs with a structured tool for innovation. The present study follows this rationale by applying QFD to the development of a ready-to-eat taro (*Colocasia esculenta*) product to illustrate both the challenges and the benefits of the approach.

### **1.3. House of Quality**

The methodology employs a series of matrices, the first and best-known being HoQ, which relates customer requirements to the technical characteristics of the product. QFD is not limited to this initial first matrix; it can also include others such as the product planning matrix, process planning matrix, and production planning matrix. HoQ represents the first stage of the QFD process. It serves as the starting point for product development by identifying and prioritizing customer needs (WHATs) and translating them into technical specifications (HOWs). In practice, HoQ facilitates communication across departments such as marketing, design, and production, ensuring that the final product reflects market expectations.

Although QFD comprises several stages, most publications and company practices tend to focus only on the HoQ (Viaene & Januszewska, 1999). Its relative simplicity, flexibility, and adaptability make it especially attractive for entrepreneurs and small businesses, even though more advanced matrices exist. For this reason, HoQ continues to represent a practical entry point for companies seeking to systematize product development without the complexity of later QFD phases.

### **1.4. Other Methodologies for the Development of New Products**

While QFD provides a structured framework for translating consumer requirements into technical specifications, it is not the only methodology supporting food product innovation. Over the last decades, several complementary approaches have been developed to enhance creativity, accelerate processes, and reduce market risk. Among them, Design Thinking emphasizes empathy with consumers and iterative problem-solving; the Stage-Gate model structures development into sequential stages with decision checkpoints; and the Lean Startup approach promotes rapid experimentation and validated learning.

Each of these methodologies brings unique strengths: Design Thinking fosters creativity, Stage-Gate ensures discipline and resource allocation, and Lean Startup increases agility and responsiveness to consumer feedback. When combined with QFD, they can create hybrid models that balance structured decision-making with flexibility and innovation. For this reason, a brief overview of these methodologies is presented below to contextualize the role of QFD within the broader landscape of new product development tools.

#### **1.4.1. Design Thinking**

Lastly, design thinking means creating new meanings. Product design is a sociotechnical endeavor that concerns both physical and social realities. According to the social constructionism theory, customers tend to assign social meanings to a product when interacting with the product. (Liu & Lu, 2020) Developing and enhancing innovative design-thinking skills is crucial in new product development. (Liu & Lu, 2020) QFD is one of the most widely adopted design methods (Liu & Lu, 2020) a combination of methods of Design Thinking and QFD can provide advantages in building products or services that align with customer needs and desires with a creative, innovative, and scalable approach. (Koswara & Alifin, 2024). The approach of Design Thinking and QFD can help understand user needs deeply and come up with innovative solutions that meet customer needs (Koswara & Alifin, 2024).

The iterative processes of Design Thinking validate identified needs and potential solutions before they are formalized in QFD. Ideation sessions generate a broader array of quality characteristics (HOWs) to meet customer requirements, which are then prioritized through QFD structured matrices. Engaging multidisciplinary teams is essential as they bring diverse perspectives throughout both methodologies. This integration leverages the human-centered focus of Design Thinking to define customer needs and apply QFD to translate those needs into specific product and process requirements, ultimately fostering a more innovative approach to product development.

### 1.4.2. Stage-Gate Model

Companies in the food sector adopt different approaches, methods, and strategies for developing new products. For example, convenience food manufacturers often apply the Stage-Gate model or milestone-based models, which generally consist of phases such as idea exploration, business case development, product testing, evaluation, and launch (Azanedo et al., 2020).

The Stage-Gate model is recognized as a structured idea-to-launch system, serving as both a conceptual and operational roadmap for managing the NPD process and increasing its effectiveness and efficiency (Cooper, 2008). This model can be compared to a sports playbook, where each play is defined to drive the project sequentially and under control, ensuring that risks are reduced and strategic decisions are taken at critical checkpoints (Cooper, 2008). The classic system involves five stages and five gates, including an initial discovery phase and a post-launch review (Cooper, 2008; Cooper et al., 2002).

#### 1.4.2.1. The States

The innovation process can be visualized as a sequence of stages, each consisting of a set of recommended activities designed to move the project forward to the next gate. Key characteristics of the stages (Cooper, 2008):

- Each stage aims to reduce uncertainties and risks by gathering information.
- The cost of each stage is higher than the previous one, representing incremental commitments but also a progressive reduction of uncertainty.
- Activities are carried out in a parallel and multidisciplinary manner, involving teams from different areas (marketing, research and development, engineering, production).
- There are no ownership stages assigned to departments — all functions contribute at every phase, promoting a holistic perspective of product development.

#### 1.4.2.2. The Gates

After each stage, the project passes through a gate — a decision point (go/kill/hold/recycle) that determines whether it should move forward, be terminated, or adjusted. The structure of each gate includes three main elements (Cooper, 2008):

1. Deliverables — tangible results presented by the team at the gate, corresponding to the activities completed in the previous stage.

2. Evaluation criteria — the parameters for decision-making, including:

- Must-meet criteria (eliminary checklist items that discard unfeasible projects);
- Should-meet criteria (scoring criteria that allow prioritization among projects).

3. Outputs — the decision taken (Go/Kill/Hold/Recycle), accompanied by an approved action plan for the next stage, including assigned resources, deadlines, and deliverables.

Thus, gates act as quality and strategic management checkpoints, ensuring that the company's resources are invested only in the most promising projects aligned with business goals.

## 1.5. Lean Startup

The Lean Startup methodology is increasingly recognized as a valuable framework for innovation and entrepreneurship. According to Blank & Eckhardt (2024), the Lean Startup can be best understood as an application of the scientific methodology to entrepreneurship. It emphasizes experimentation, iterative development, and validated learning, rather than relying on lengthy planning cycles and assumptions.

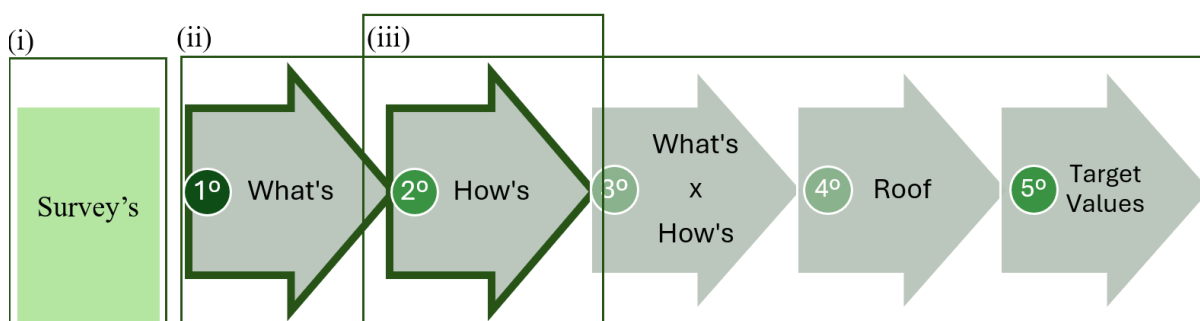
In the context of NPD, Lean Startup promotes the creation of a minimum viable product (MVP) that allows entrepreneurs to test hypotheses directly with customers. Feedback collected from these early interactions guides further product iterations, ensuring that development is grounded in real market needs and reducing the

risk of failure. By incorporating Lean Startup principles, the QFD methodology can become more agile, customer-centric, and adaptable, enabling companies to develop products that better meet market expectations with greater efficiency. This integration offers the potential to align QFD's structured, systematic approach with Lean Startup's flexibility and rapid learning cycles, resulting in a more effective innovative process.

## 2. Methods

This study employed a mixed-method approach, combining a literature review with a practical application of the QFD methodology. The process focused on the development of a ready-to-eat taro (*Colocasia esculenta*) product, using consumer data as the foundation for building HoQ. The methodology involved three main stages: (i) identification of consumer requirements through surveys, (ii) translation of these requirements into technical characteristics, and (iii) construction of the HoQ to guide product planning. The following workflow illustrates the methodological steps followed in this study, from the literature review to the final conclusions.

**Figure 1:** Methodological workflow of the study (author's elaboration).



## 3. Results — House of Quality

The first step in the first HoQ is to identify the customers' requirements. To achieve this, surveys were conducted to understand the consumers' needs, as well as their importance and relevance. Customers' requirements were rated on a scale of 1 to 5. A total of 24 responses were collected through online surveys, between 3<sup>rd</sup> and 6<sup>th</sup> February 2025.

### 3.1. Consumer's Requirements (Whats) or "Voice of Customer"

The construction of HoQ begins with the identification of consumer demands, commonly referred to as the (Whats) (Benner et al., 2003), the (Whats) were identified through an online survey. The results confirmed the importance of attributes such as taste, health, and convenience, which are in line with broader innovation trends in the agri-food sector. Respondents evaluated factors such as taste, convenience, texture, health, sustainability, allergen-free options, and origin certification on a five-point Likert scale. Results revealed that taste (mean score 4.8/5), health (4.2/5), and convenience (3.9/5) were the most valued attributes. These findings are consistent with previous studies emphasizing consumer preference for healthier and more practical food options (Stewart-Knox & Mitchell, 2003; Costa et al. 2006)

This first stage focuses on VoC, a structured list of product attributes that must be fulfilled. Establishing the VoC is considered the most critical step in QFD projects (Costa et al., 2000). Incorporating consumer requirements early in the NPD process has been recognized as a decisive success factor (van Kleef et al., 2005), since consumer research is relatively inexpensive compared to the potential cost of market failure. At this stage of the HoQ, the QFD team must ensure a clear understanding of what consumers demand from the product and how these demands align with the company's strategic objectives (Costa et al., 2000). This involves capturing both qualitative dimensions (what consumers value in general) and quantitative dimensions (the relative importance of each attribute) (Viaene & Januszewska, 1999). Such a structured identification of consumer requirements forms the foundation for subsequent translation into technical specifications in HoQ. Figure 2 presents the ranked list of consumer requirements (Whats) and their relative importance.

**Figure 2:** Consumer's requirements (author's elaboration).



Whats — “Voice of the Customer”	
Convenience	5
Taste	5
Healthy	4
Allergen free (Gluten/ Lactose free)	2
Origin Certificates (IGP/ Organic)	3
Sustainability	3
Texture	4

The results confirmed that taste, health, and convenience (ready-to-eat) were the most valued attributes, followed by texture and sustainability-related factors such as certified origin and allergen-free claims. These findings are consistent with previous studies emphasizing consumer preference for healthier, more practical, and trustworthy food options (Stewart-Knox & Mitchell, 2003; Costa et al., 2006; van Kleef et al., 2005). Moreover, evidence from innovation challenges such as ECOTROPHELIA Portugal reinforces this alignment, with finalist products most frequently highlighting convenience, health, and tradition, particularly within categories such as snacks (34.1 %), desserts (17.1 %), and ready meals (12.2 %) (Cardoso & Oliveira, 2021).

### 3.2. Product’s Requirements (Hows)

The (HOWs) represent the technical characteristics established to meet the consumer requirements identified in the survey. For the ready-to-eat taro (*Colocasia esculenta*) product, these technical specifications were defined to ensure safety, quality, and alignment with consumer expectations. They include: **(i) preparation time**, with the product designed to be ready to eat in  $\leq 5$  minutes and ensuring  $\text{pH} < 4.5$  and a minimum shelf life of  $\geq 30$  days; **(ii) taste evaluation**, requiring a minimum sensory acceptance score of  $\geq 80\%$ ; **(iii) Low Sugar/Fat content**, limiting sugar to  $< 0.5$  g/100 g, fat to  $< 1.5$  g/100 g, and sodium to  $< 120$  mg per portion; **(iv) allergen-free**, formulation, verified through laboratory testing for gluten and lactose; **(v) certified suppliers**, ensuring ingredient traceability, IGP origin verification, and compliance with “*Produto da Madeira*” certification; **(vi) sustainability**, including raw materials sourced from certified organic producers and the use of recyclable or biodegradable packaging; and **(vii) selection of taro cultivar**, guaranteeing stable sensory characteristics and consistent quality across batches. These technical specifications summarize the product requirements that guide formulation, processing, and quality control in the development of the ready-to-eat taro (*Colocasia esculenta*) product. **Figure 3** presents the technical requirements (HOWs) identified for this product.

**Figure 3:** Product’s requirements (author’s elaboration).

Hows
<b>(i) Preparation time</b> Product ready to eat ( $\leq 5$ minutes) $\text{pH} < 4.5$ ; Shelf life $\geq 30$ days
<b>(ii) Taste Evaluation</b> Minimum sensory acceptance score of $\geq 80\%$ . Controlled cooking temperature/time
<b>(iii) Low Sugar/Fat content</b> Nutritional Targets: sugar $< 0.5$ g/100g; fat $< 1.5$ g/100g; sodium $< 120$ mg/portion
<b>(iv) Allergen free</b> Gluten/ Lactose free Validated allergen-free formulation/ Laboratory verification



<p><b>(v) Certified suppliers</b>                  Certified suppliers ensuring traceability, IGP origin verification, and compliance with the “<i>Produto da Madeira</i>” certification.</p>
<p><b>(vi) Sustainability</b>                  Selection of raw materials from certified organic producers; use of recyclable/ biodegradable packaging;</p>
<p><b>(vii) Selected taro cultivar</b>                  Use of a taro cultivar with stable sensory characteristics and consistent quality across batches.</p>

### 3.3. Matrix — Relationship Whats x Hows

The relationship matrix connects consumer requirements (Whats) with technical requirements (Hows), enabling the identification and prioritization of actions with the greatest impact on consumer satisfaction (Bech et al., 1997). Each relationship was classified as strong, medium, or weak according to the scoring system proposed by Benner et al. (2003), where strong = 9, medium = 3, and weak = 1.

**Figure 4:** Relationship between the Whats and Hows (author’s elaboration).

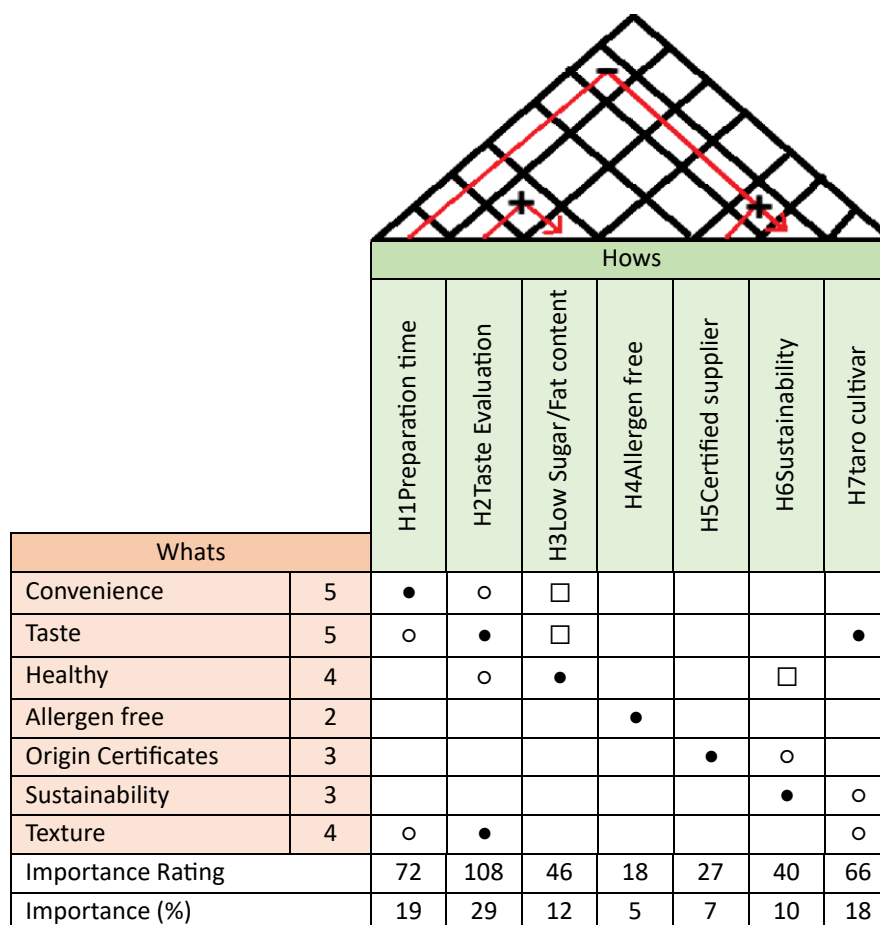
● (9)	Strong Relationship
○ (3)	Medium Relationship
□ (1)	Weak Relationship

Based on this scale, the relationship matrix was constructed to connect consumer demands with technical specifications. This matrix constitutes the core of the HoQ, as it visualizes how strongly each consumer requirement is supported by the defined technical parameters. Beyond highlighting direct relationships, the matrix also acts as a diagnostic tool, as blank rows or columns indicate either that a consumer requirement has not been adequately translated into a technical specification, or that a technical feature does not respond to any identified consumer need (Benner et al., 2003). Although some authors describe the four-phase QFD approach, most food industry applications focus primarily on this first matrix, the HoQ, as it provides essential insights into trade-off decisions and product improvement opportunities (Benner et al., 2003).

Results revealed strong relationships between: (i) convenience and preparation time; (ii) taste and both taste evaluation and taro cultivar; (iii) health and low sugar/fat content; and (iv) texture and taste evaluation. Figure 5 illustrates the relationship matrix between (Whats) and (Hows), highlighting strong, medium, and weak correlations.



Figure 5: Matrix: relationship Whats x Hows (author’s elaboration).



Once the first HoQ has been constructed, it is possible to extend the analysis by developing additional matrices, such as process planning or production planning matrices, to further support decision-making throughout product development. However, in practice, many development teams limit themselves to the initial HoQ.

### 3.4. Roof of the HoQ

The roof of the HoQ represents the correlation matrix, which identifies positive and negative interdependencies among the technical requirements (HOWs) (Benner et al., 2003). These correlations indicate where actions may support or conflict with one another during product development. In this study, positive correlations were observed between taste evaluation and low sugar/fat content, as well as between certified suppliers and sustainability. These synergies suggest that improvements in one parameter can reinforce the other, strengthening the overall product concept. Conversely, a negative correlation was identified between preparation time and sustainability, indicating a potential trade-off between achieving quick preparation and maintaining environmentally responsible production practices. Recognizing these correlations is essential for balancing product attributes and anticipating conflicts during development (Cohen, 1995). Figure 6 presents the correlation matrix (roof) of the HoQ, showing the positive and negative interactions among the HOWs.



Figure 6: Roof of the HoQ (author’s elaboration).

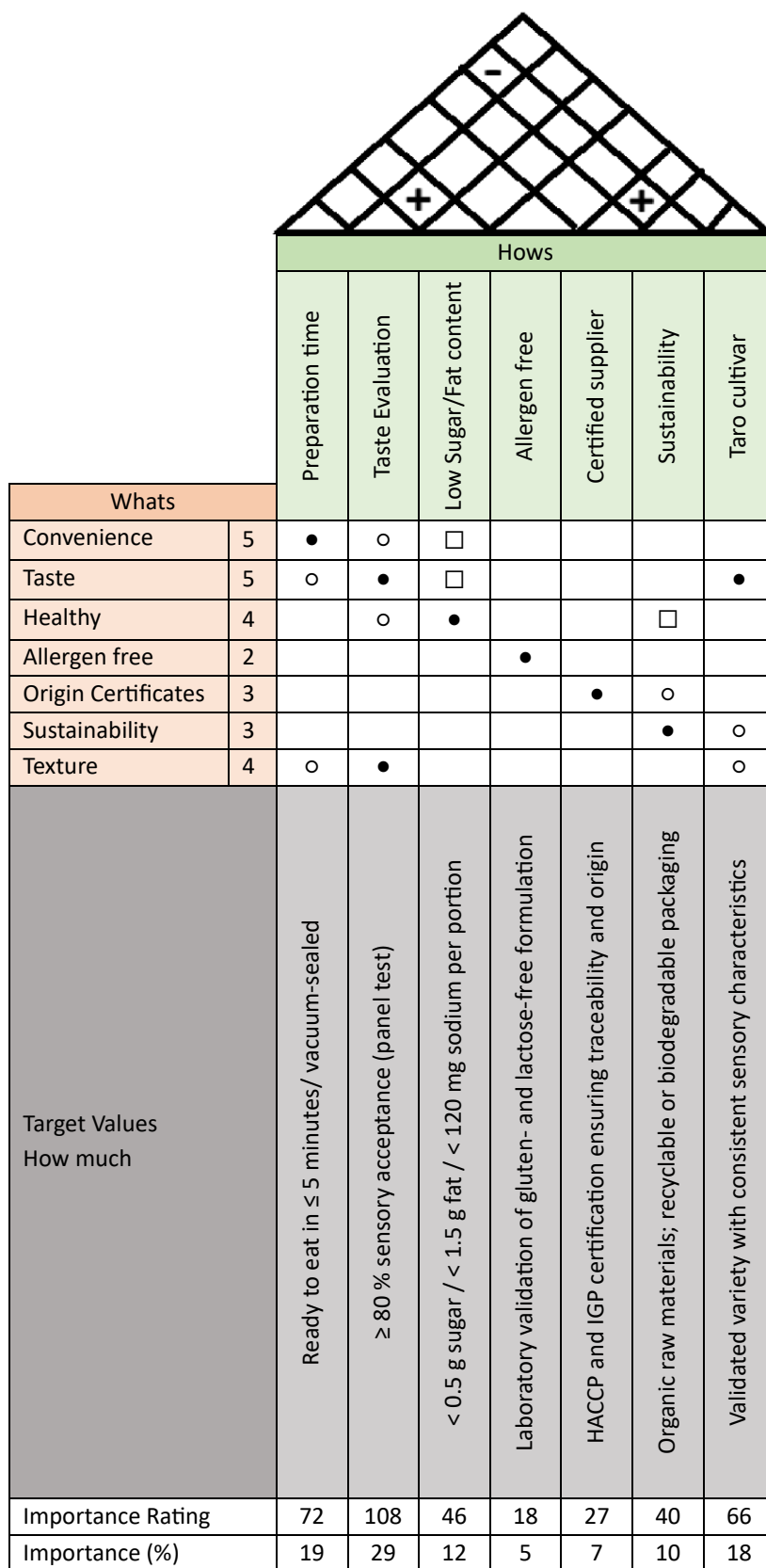
Whats		Hows						
		Preparation time	Taste Evaluation	Low Sugar/Fat content	Allergen free	Certified supplier	Sustainability	Taro cultivar
Convenience	5	●	○	□				
Taste	5	○	●	□				●
Healthy	4		○	●			□	
Allergen free	2				●			
Origin Certificates	3					●	○	
Sustainability	3						●	○
Texture	4	○	●					○
Importance Rating		72	108	46	18	27	40	66
Importance (%)		19	29	12	5	7	10	18

### 3.5. Target Values How Much

Target values were established for each technical requirement to ensure alignment between product specifications and consumer expectations. The cooking process was optimized so that, once packaged, the product can be reheated and ready to eat within ≤ 5 minutes, ensuring convenience while maintaining taste and texture. Shelf life was set at a minimum of 30 days under refrigerated storage, supported by vacuum packaging to guarantee microbiological stability. Nutritional targets were defined as sugar < 0.5 g/100 g, fat < 1.5 g/100 g, and sodium < 120 mg per portion, in line with industry standards for healthy products. Additional targets included laboratory validation of allergen-free formulation (gluten and lactose), supplier certification under HACCP and IGP schemes to ensure traceability and origin integrity, and the use of a validated taro cultivar to guarantee batch-to-batch sensory consistency. Sustainability objectives were addressed through the selection of organic raw materials and the adoption of recyclable or biodegradable packaging solutions. These quantitative benchmarks represent the How Muchs of the HoQ and provide measurable goals for product development, supporting analysis, optimization, and consistency in meeting consumer expectations (Benner et al., 2003). Figure 7 presents the complete HoQ for the ready-to-eat taro (*Colocasia esculenta*) product, integrating consumer requirements (WHATs), technical requirements (HOWs), correlations, and corresponding target values.



Figure 7: Complete HoQ for the ready-to-eat taro (*Colocasia esculenta*) product (author’s elaboration).



## 4. Discussion

The application of the QFD methodology to the development of a ready-to-eat taro (*Colocasia esculenta*) product proved effective in aligning technical specifications with consumer requirements. HoQ facilitated the translation of consumer preferences, such as taste, convenience, and health, into measurable targets, including nutritional composition, shelf life, and packaging solutions. At the same time, the process revealed challenges typical of the food industry, such as balancing technical feasibility with consumer expectations and managing trade-offs between sensory quality and nutrient preservation.

These results mirror innovation trends observed in initiatives like ECOTROPHELIA Portugal, where finalist products have consistently emphasized convenience, health, and tradition. Snacks (34.1%), desserts (17.1%), and ready meals (12.2%) dominated submissions, with common features including bioactive compounds (34.2%), reduced sugar/fat content (19.0%), and gluten/lactose-free formulations (19.0%) (Cardoso & Oliveira, 2021). The emphasis on health attributes aligns with industry-wide efforts to improve nutritional profiles through sugar and fat reduction (Cardoso & Oliveira, 2021). Previous research also indicates that reduced-fat products tend to achieve stronger market performance, likely because they respond directly to consumer health concerns and retailer strategies (Stewart-Knox & Mitchell, 2003).

From a managerial perspective, integrating QFD into NPD requires organizational preparation. Training is essential for marketing, research and development, and production teams to understand the logic of the HoQ and interpret consumer data effectively. While initial applications are time and resource intensive, subsequent use becomes more efficient once routines and templates are established (Benner et al., 2003). For small and medium sized enterprises, the main challenge is the opportunity cost of skilled human resources; however, the potential reduction in market failure risk and improved alignment with consumer needs typically outweigh the initial investment.

Therefore, companies should adopt a phased approach to implementation:

- **Pilot phase** — small scale projects to build capacity and achieve quick wins.
- **Integration phase** — systematic use of the HoQ within NPD processes by cross functional teams.
- **Consolidation phase** — expansion to additional QFD matrices (e.g., process or production planning), ensuring continuous improvement.

This study also presents limitations. The sample was small ( $n = 24$ ), limiting generalizability. Moreover, the methodology was applied in a conceptual framework rather than an industrial context, meaning that practical constraints such as production costs, supply chain variability, and regulatory requirements were not fully tested. Future research should therefore validate the methodology in real industrial settings and explore hybrid approaches combining QFD with complementary tools such as Design Thinking, Stage-Gate, or Lean Startup.

### 4.1. Opportunities

Despite these challenges, the adaptation of QFD to the food sector offers several opportunities. First, it enables companies to systematically integrate consumer insights into product development, thereby increasing the likelihood of market success and reducing failure rates. Second, it fosters cross-functional collaboration by structuring communication between marketing, research and development, and production an area where small and medium sized enterprises often face difficulties.

QFD also supports the development of healthier and more sustainable food products, addressing regulatory pressures and consumer expectations regarding nutrition, allergen-free options, and environmental impact. By aligning with these market trends, QFD serves not only as a development tool but also as a means of strategic differentiation. Finally, its relatively low financial cost compared to other innovation frameworks makes QFD accessible to entrepreneurs in emerging markets, democratizing structured product development and allowing smaller companies to compete more effectively.

## 5. Conclusions

This study demonstrated how QFD can be applied to the development of a ready-to-eat taro (*Colocasia esculenta*) product, systematically translating consumer requirements into technical specifications through the HoQ. The final HoQ confirmed that consumer priorities can be effectively converted into engineering attributes, proving the usefulness of QFD in food product development. These findings align with recent research highlighting QFD's relevance for innovation in food and packaging design (Indraswari et al., 2024; Mudgal et al., 2024; Peres et al., 2025). Furthermore, defining measurable technical targets supports the transition towards data-driven quality management in line with Quality 4.0 principles (Santoso et al., 2024).

This work also advances the literature by addressing a ready-to-eat root-based product (taro) with explicit microbiological and nutritional parameters, and by embedding regional certification “*Produto da Madeira*” within the HOW “Certified suppliers” (IGP). This strengthens the link between QFD, traceability, and territorial identity—dimensions rarely explored in recent studies (Siwiec et al., 2025; Wicaksono et al., 2025).

From a managerial perspective, QFD enhances the alignment between innovation and consumer expectations—particularly regarding taste, convenience, health, and sustainability. Although implementation requires investment in training, time, and cross-functional teamwork, these costs are offset by long-term benefits such as reduced risk of market failure and increased consumer trust. For entrepreneurs and SMEs, QFD represents a structured yet flexible framework for consumer-driven innovation.

Some limitations must nevertheless be acknowledged. The small sample size and the conceptual rather than industrial application restrict the generalizability of the findings. Future research should extend this analysis to industrial environments and explore hybrid approaches combining QFD with methodologies such as Design Thinking, Stage-Gate, or Lean Startup. In addition, integrating QFD with tools like Life Cycle Assessment (LCA), IoT-based monitoring, and data analytics could reinforce its alignment with the Quality 4.0 paradigm and support measurable sustainability performance.

In conclusion, QFD—through the systematic integration of WHATs and HOWs—offers both theoretical contributions to food innovation literature and practical guidance for companies. Its adaptation to the food sector represents not only a methodological framework but also a strategic pathway for building consumer-driven, sustainable, and competitive innovations. Ultimately, QFD's adaptation to food entrepreneurship represents more than a technical exercise: it redefines innovation as the measurable translation of human needs into sustainable, market-viable solutions.

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## Appendices

Survey, the survey was carried out between the 3<sup>rd</sup> and 6<sup>th</sup> of February, the survey was answered by 24 people online.

- When buying food products, what importance do you attach to the factor: **Allergens free**

(1) Nothing important 10 responses

(2) Unimportant 4 responses

(3) Moderately Important 3 responses

(4) Important 2 responses

(5) Very important 5 responses

Total:  $60 = (10 \times 1) + (2 \times 4) + (3 \times 3) + (4 \times 2) + (5 \times 5)$

- When buying food products, what importance do you attach to the factor: **Convenience**

(1) Nothing important 1 responses

(2) Unimportant 0 responses

(3) Moderately Important 5 responses

(4) Important 11 responses

(5) Very important 7 responses

Total:  $95 = (1 \times 1) + (2 \times 0) + (3 \times 5) + (4 \times 11) + (5 \times 7)$

- When buying food products, what importance do you attach to the factor: **Texture**



(1) Nothing important 0 responses  
 (2) Unimportant 0 responses  
 (3) Moderately Important 9 responses  
 (4) Important 7 responses  
 (5) Very important 8 responses  
 Total:  $95=(1\times 0)+(2\times 0)+(3\times 9)+(4\times 7)+(5\times 8)$

- When buying food products, what importance do you attach to the factor: **Taste**

(1) Nothing important 0 responses  
 (2) Unimportant 0 responses  
 (3) Moderately Important 0 responses  
 (4) Important 3 responses  
 (5) Very important 21 responses  
 Total:  $117=(1\times 0)+(2\times 0)+(3\times 0)+(4\times 3)+(5\times 21)$

- When buying food products, what importance do you attach to the factor: **Origin Certificate**

(1) Nothing important 10 responses  
 (2) Unimportant 4 responses  
 (3) Moderately Important 3 responses  
 (4) Important 2 responses  
 (5) Very important 5 responses  
 Total:  $60=(1\times 10)+(2\times 4)+(3\times 3)+(4\times 2)+(5\times 5)$

- When buying food products, what importance do you attach to the factor: **Healthy**

(1) Nothing important 0 responses  
 (2) Unimportant 1 responses  
 (3) Moderately Important 3 responses  
 (4) Important 9 responses  
 (5) Very important 11 responses  
 Total:  $102=(1\times 0)+(2\times 1)+(3\times 3)+(4\times 9)+(5\times 11)$

- When buying food products, what importance do you attach to the factor: **Sustainability**

(1) Nothing important 1 responses  
 (2) Unimportant 2 responses  
 (3) Moderately Important 11 responses  
 (4) Important 7 responses  
 (5) Very important 3 responses  
 Total:  $81=(1\times 1)+(2\times 2)+(3\times 11)+(4\times 7)+(5\times 3)$

Importance (rates)			
Taste	117/24	4,8	<b>5</b>
Healthy	102/24	4,2	<b>4</b>
Convenience	95/24	3,9	<b>4</b>
Texture	95/24	3,9	<b>4</b>
Sustainability	81/24	3,3	<b>3</b>
Origin Certificate	60/24	2,5	<b>2</b>



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### Ethical Statement

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**Conflict of Interest:** Nothing to declare. **Funding:** Nothing to declare. **Peer Review:** Double-blind.



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## Technological innovation and management in rehabilitation nursing: Challenges and solutions in the Portuguese context

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### Abstract

This article investigates the challenges and opportunities associated with the integration of technological innovations in rehabilitation nursing, with a particular focus on the Portuguese context and its international connections. Drawing on a narrative literature review, complemented by the analysis of two practical case studies, it identifies cultural, financial, and organisational barriers, as well as the transformative potential of solutions such as artificial intelligence, telemedicine, and assistive devices. Despite the clear benefits of these technologies in personalising care and optimising resources, their implementation remains constrained by infrastructural limitations, institutional resistance, and gaps in professional training. International reference experiences—such as those of the Mayo Clinic, the Cleveland Clinic, and the Spanish KiReS system—is compared with national initiatives coordinated by the Escola Superior de Enfermagem de Coimbra (ESENFC), through TecCare, the Health Sciences Research Unit: Nursing (UICISA: E), and with the support of the Agência Nacional de Inovação (ANI). Projects such as the Subcutaneous Hydration Device (DHS), DigiNurse, and smart clothing for the prevention of pressure ulcers demonstrate how academic entrepreneurship can drive innovative clinical solutions that are scientifically validated and tailored to the real needs of the healthcare system. The original contribution of this study lies in the critical articulation between international and national experiences and in the interface between strategic management, technological innovation, and the humanisation of care. It concludes that this integrated model represents a promising pathway to generate measurable improvements in clinical outcomes and to support sustainable advances in the healthcare sector.

**Keywords:** Health Entrepreneurship; Healthcare Management; Personalised Care; Rehabilitation Nursing; Technological Innovation.

### 1. Introduction

Innovation is the driving force that propels healthcare into the future. Addressing today's challenges with tomorrow's solutions is the essence of progress (Leite, 2024). In rehabilitation nursing, this perspective is particularly relevant, as this field is crucial for the recovery of patients with chronic conditions or following traumatic events. The incorporation of innovations into management and clinical practice, therefore, becomes a decisive factor for improving care and clinical outcomes (Lau, 2021).

However, one of the greatest challenges that persists in the healthcare sector is the effective integration between technological advances and the personalisation of care. Despite progress achieved, a significant gap remains between technical innovation and its practical translation, particularly in meeting patients' specific needs. Recent studies highlight the transformative potential of emerging technologies. Guarducci et al. (2025), for instance, investigate the applicability of wearable sensors for remote monitoring, underscoring their usefulness in optimising care. Similarly, Christensen, Grossman and Hwang (2009) argue that disruptive technological solutions can reshape healthcare services, increasing accessibility and efficiency, especially in resource-limited settings.

It is important to recognise, however, that healthcare innovation is not merely a technical process, but also an organisational, strategic, and pedagogical phenomenon, with implications for professional culture and the training of future nurses. In this context, the role of academic entrepreneurship as a catalyst for innovation is of



relevance. A concrete example is the Escola Superior de Enfermagem de Coimbra (ESEnfC), which, in collaboration with the Health Sciences Research Unit: Nursing (UICISA: E) and with the support of the Agência Nacional de Inovação (ANI), has developed high-impact projects such as DigiNurse — which validates digital competencies in nursing students (Parreira, Santos-Costa & Graveto, 2021) — smart textiles for the prevention of pressure ulcers (Salgueiro-Oliveira, Parreira & Martins, 2023), and studies on digital literacy in nursing (Gonçalves, Parreira & Salgueiro-Oliveira, 2022).

This article, therefore, aims to understand how the integration of emerging technologies—such as artificial intelligence, telemedicine, wearable devices, and assistive solutions—can transform the practice of rehabilitation nursing. The objective is to identify cultural, organisational, and financial barriers that hinder the adoption of innovations; to analyse how strategic management and academic entrepreneurship can facilitate this integration, and to propose strategies that ensure an ethical, humanised, and sustainable implementation.

By articulating international literature with validated local experiences, this study offers a critical reflection on the challenges and opportunities of technological innovation in rehabilitation nursing, contributing evidence and practical proposals for managers, healthcare professionals, and policymakers committed to the modernisation of care.

## **2. Management in Rehabilitation Nursing**

Management is a central element for the success of rehabilitation nursing, being essential for the efficient coordination of care and the optimisation of resources, with direct impacts on clinical outcomes and patient satisfaction (Porter & Teisberg, 2006). Classical models, such as competency-based management and outcomes-based management, play a key role in defining responsibilities and measuring performance against concrete metrics (Donabedian, 1988; Greenhalgh et al., 2018). Furthermore, established practices such as the use of information systems and continuous professional training have proven effective in improving care (Kitson et al., 2013).

However, the healthcare sector faces significant challenges in adapting traditional models to a constantly evolving digital environment. The integration of innovative technologies, such as telemedicine and assistive devices, not only transforms care but also requires new forms of organisation and management (Wang et al., 2024). In the context of rehabilitation nursing, entrepreneurial strategies are increasingly relevant, enabling the efficient allocation of resources and a more effective response to patients' needs (Wong, Leung & Wang, 2020)

Authors such as Kwak and Lee (2022) emphasise that overcoming cultural and organisational resistance is essential for the full adoption of technological innovations. This transformation demands resilient managers capable of fostering an organisational culture open to change and of leading their teams with confidence and clarity in times of uncertainty.

The adoption of innovative technologies in rehabilitation nursing faces multiple obstacles, ranging from cultural dimensions to organisational barriers. As highlighted by Herzlinger (2006), Greenhalgh et al. (2017), Kim and Lee (2022), Johnson and Martinez (2024), and Nguyen (2024), such barriers can compromise the effectiveness of implementation but may also be overcome through appropriate management strategies. Table 1 summarises these barriers and provides practical examples in the healthcare sector, as well as the main approaches to addressing them.

The study by Kim and Lee (2022) highlights several cultural and organisational barriers to the adoption of technological innovations, identifying ways to overcome them:

**Table 1:** Barriers and strategies for the implementation of technologies: a focus on the healthcare sector

Category	Description	Example in the healthcare sector
<b>Cultural barriers</b>		
Fear of the unknown	Staff fear losing control or being replaced by technologies.	Fear of AI and wearable devices replacing professionals.
Risk-averse culture	Organisations that distrust failure tend to resist change.	Reluctance to adopt disruptive technologies such as telemedicine.
Distrust in technologies	Lack of understanding of the benefits of new technologies.	Resistance to remote monitoring software by healthcare professionals.
<b>Organisational barriers</b>		
Lack of training	The absence of training programmes hinders adaptation to new technologies.	Healthcare professionals without adequate training in new technological systems.
Weak leadership	Lack of visionary leadership to guide the team in the transition to innovation.	Management is unable to prioritise and clearly communicate the importance of innovations.
Insufficient resources	Lack of funding and adequate infrastructure limits implementation.	Hospitals with low budgets for the acquisition and installation of telemedicine systems.
<b>Overcoming barriers</b>		
Continuous training	Invest in adequate training for healthcare professionals.	Implement regular training programmes for the use of assistive devices.
Clear leadership	Clearly communicate the benefits of new technologies.	Leadership that explains the positive impact of innovation on patients and organisational efficiency.
Culture of innovation	Promote a culture open to change and experimentation.	Encourage the experimental use of AI with technical support, followed by outcome analysis.
Gradual implementation	Introduce technologies progressively, with ongoing technical support.	Adopt telemedicine initially in specific departments before expanding across the entire organisation.

**Source:** Own elaboration, adapted from Herzlinger (2006), Greenhalgh et al. (2017), Kim and Lee (2022), Johnson and Martinez (2024), and Nguyen (2024).

Table 1 summarises the main barriers to the adoption of technological innovation in rehabilitation nursing, highlighting cultural, organisational, and infrastructural dimensions. This categorisation is consistent with classical analyses, such as Herzlinger (2006), who emphasises the difficulty of cultural change in the healthcare sector, and Greenhalgh et al. (2017), who underline the challenges of sustainability in technological adoption. More recently, studies such as Kim and Lee (2022) and Johnson and Martinez (2024) reinforce the idea that organisational resistance and the absence of clear leadership are central obstacles, while Nguyen (2024) and Lee and Patel (2024) point to the need for continuous training as an essential strategy to overcome these barriers.

Kwak and Lee (2022) suggest that, with adequate leadership and sustained support, the barriers to technological innovation can be overcome, resulting in improvements in patient care and efficiency within healthcare organisations. Chheang et al. (2023) further stress that personalisation of care, when integrated with innovative technologies, can significantly enhance both the efficiency and the effectiveness of services.

The identification of specific niches within healthcare services also emerges as a promising solution. According to Herzlinger (2006), adapting resources and strategies to meet the needs of different groups of patients is an underutilised yet highly valuable approach in the context of rehabilitation nursing.



Finally, effective management in the healthcare sector must go beyond achieving operational results, requiring flexibility, strategic vision, and the capacity to respond swiftly to legislative and clinical changes. Managerial resilience thus becomes an indispensable competence, enabling organisations to maintain a consistent focus on patient needs even in dynamic and unpredictable environments. Moktadir et al. (2018) address the survival of supply chains in the era of Industry 4.0, highlighting the need to adapt to new technologies to ensure resilience and operational efficiency. Their analysis illustrates how digitalisation, automation, and artificial intelligence can optimise hospital logistics, reduce waste, and ensure agile responses to healthcare crises. This balance between innovation and adaptation is crucial to ensuring that rehabilitation services not only keep pace with change but also lead transformations within the sector.

### **2.1. Innovation in Rehabilitation Nursing**

Healthcare innovation must be patient-oriented, encouraging active participation in the definition and evaluation of care. Herzlinger (2006) emphasises that patient-centred innovation is crucial for ensuring effectiveness, informed choice, and satisfaction in contemporary healthcare systems.

Innovation plays an essential role in transforming and enhancing the quality of care delivered in rehabilitation nursing. Emerging technologies such as telemedicine and assistive devices have made a significant contribution to the personalisation and optimisation of treatments, resulting in improved clinical outcomes. For example, telemedicine facilitates remote monitoring and continuity of care, enabling professionals to follow patients more effectively (Dinesen et al., 2016). Likewise, robotic therapy and artificial intelligence have revolutionised rehabilitation treatments, offering more personalised and efficient approaches (Maciejasz et al., 2014; Wong, Leung & Wang, 2020).

These technological innovations not only increase the efficiency of treatments but also create opportunities for recovery and patient satisfaction, as highlighted by Topol (2019). Innovation in the healthcare sector operates bilaterally: while it drives the development of new technologies, these also create opportunities to transform the sector. Khatib et al. (2021, *Technological Forecasting & Social Change*) investigate the relationship between digital transformation and financial sustainability, stressing how emerging technologies such as big data and advanced algorithms can optimise financial management in healthcare. The implementation of predictive analytics and financial automation tools may be particularly relevant for hospitals and clinics integrating wearable medical devices and telemedicine solutions, thereby ensuring a viable and competitive business model.

#### **2.1.1. Authors' Perspectives on Innovation**

The table below summarises the main contributions from recent literature on innovation in the context of rehabilitation nursing.

**Table 2:** Authors and Perspectives on Innovation.

Author(s) and Year	Perspective on Innovation
Gómez-Jorge et al. (2025)	They discuss how business innovations, particularly in healthcare start-ups, provide creative solutions to challenges in rehabilitation. In rehabilitation nursing, this translates into the use of technologies and innovative processes aimed at improving patient outcomes.
Wang et al. (2024)	They argue that telemedicine has the potential to transform rehabilitation care, making it more accessible and effective.
(Wong, Leung & Wang, 2020)	They highlight the use of artificial intelligence and robotics as crucial innovations for personalising treatments and enhancing efficiency in patient recovery.
Lee & Kim (2022, <i>BMC Medical Informatics and Decision Making</i> )	They point out that barriers to innovation can be overcome with strategies that include adequate training and organisational support, which are essential for implementing new technologies in rehabilitation nursing.
Keesara et al. (2020, <i>New England Journal of Medicine</i> )	They emphasise the importance of directing innovation towards specific niches, ensuring that emerging technologies meet the concrete needs of patient groups. In rehabilitation nursing, this may include the personalisation of assistive devices for different clinical conditions.

**Source:** Adapted from Gómez-Jorge et al. (2025), Wong, Leung & Wang (2020), Lee & Kim (2022), Keesara et al. (2020), Greenhalgh et al. (2017), and Herzlinger (2006).

Table 2 indicates that authors broadly agree on the value of technological innovation as a driver of transformation in rehabilitation nursing, highlighting solutions such as telemedicine, artificial intelligence, robotics, and entrepreneurship. Divergences emerge mainly in emphasis: while some advocate for technological expansion, others stress the importance of overcoming organisational and cultural barriers, ensuring adequate training and adaptation to the specific needs of patients.

### 2.1.2. Humanisation and Technology: The Necessary Balance

Alves et al. (2024), in a systematic review published in *Heliyon*, examine outcomes from structured home-based rehabilitation programmes for older adults, highlighting clinical benefits and implications for the digital empowerment of patients and nursing teams. The study also highlights the opportunities and challenges of AI adoption in nursing practice, including ethical barriers, professional training, and technological acceptance — all essential aspects for the strategic development of new solutions in healthcare.

The focus must remain on improving the relationship between patient and healthcare professional, promoting empathy and humanised care. Wong, Leung and Wang (2020) argue that the use of AI and robotics should be accompanied by strategies ensuring that technology acts as a facilitator of care, rather than as a barrier.

Furthermore, Topol (2019) emphasises that while technological innovation can enhance efficiency, the patient must remain at the centre of the process, ensuring that new tools serve as support mechanisms for humanised care. This balance is fundamental for turning technological challenges into genuine opportunities for improving rehabilitation care, promoting not only clinical advances but also a more satisfactory patient experience.

## 2.2. Entrepreneurship in the Healthcare Domain

Entrepreneurship is regarded as an effective approach for fostering innovation and improving the management of healthcare services, including rehabilitation.

Leite et al. (2024) provide key insights into how entrepreneurship can be applied in healthcare, using technological innovations to develop new services and products that address emerging needs in rehabilitation.



Similarly, Mauro et al. (2024, *Technological Forecasting & Social Change*) support the view that entrepreneurship-driven innovation is essential for expanding access to rehabilitation treatments, highlighting how start-ups can offer tailored solutions for diverse patient needs.

Other authors, such as Chheang et al. (2023), contribute by discussing how entrepreneurship can support the development of care models based on AI and robotics, two promising areas within rehabilitation nursing.

Kwak and Lee (2022) stress that entrepreneurship-driven innovation must include strategies to overcome organisational resistance, which is crucial for introducing new practices and technologies in rehabilitation nursing.

Walden et al. (2020, *Journal of Clinical and Translational Science*) argue that entrepreneurship in healthcare can identify profitable niches within rehabilitation services, such as assistive technologies, and expand the market reach of these innovations.

Entrepreneurship in healthcare has long been viewed as a way of stimulating innovation, but today it is more critical than ever, as noted by Leite et al. (2024). It can serve as a mechanism for breaking bureaucratic barriers that often hinder the rapid implementation of new ideas in healthcare. However, it is vital that entrepreneurship in this field is guided by strong ethical principles and ultimately aims at patient well-being.

In this regard, Gómez-Jorge, Bermejo-Olivas, Díaz-Garrido, and Soriano-Pinar (2025), in the *International Entrepreneurship and Management Journal*, analyse the impact of self-esteem and entrepreneurial orientation on success in healthcare entrepreneurship. Their study underscores how healthcare professionals' confidence and entrepreneurial vision can be decisive in implementing innovative solutions, stressing the importance of promoting entrepreneurial training within healthcare management to achieve sustainable and effective impact.

More recently, Gkiolnta et al. (2025) focus on the role of innovations in rehabilitation, advocating that technological adoption must be accompanied by ethical analysis and practical assessment of its impact on care. While many start-ups have invested in innovative technological solutions, the authors stress that this approach must be balanced with a human-centred vision of care, ensuring that innovations are not only economically viable but also practical and effective in everyday rehabilitation settings.

### 3. Methodology

This study adopts a qualitative exploratory approach, structured as a narrative literature review complemented by the analysis of practical cases. The choice of a narrative review is justified by the multidimensional complexity of technological innovation in rehabilitation nursing and the need to integrate different types of sources (scientific articles, institutional reports, and regulatory documents), without the rigidity of systematic protocols (Creswell, 2014).

#### 3.1. Methodological Structure

Scope, sources, descriptors, criteria, and case logic. We conducted a narrative literature review across PubMed, Scopus, Web of Science, and national resources (RCAAP, SciELO Portugal), complemented by Google Scholar for institutional/grey literature, covering 2020–2025 and including works in Portuguese or English. We combined descriptors such as nursing innovation, rehabilitation nursing, digital health, entrepreneurship in nursing, and artificial intelligence with Boolean operators. Inclusion criteria comprised peer-reviewed articles and official documents (e.g., ANI, WHO, UNESCO) relevant to technological innovation in rehabilitation nursing; exclusion criteria removed duplicates, non-peer-reviewed/opinion pieces, and purely technical documents without clinical linkage. To complement the review, we purposively selected two Portuguese cases—Subcutaneous Hydration Device (DHS) and DigiNurse—based on theoretical relevance, prior scientific validation/usability, and practical applicability to rehabilitation/home-palliative care and digital capacity-building, respectively; this corpus was then fed into the subsequent triangulation stage. The literature search was last updated on 20 September 2025.



### 3.1.1. Methodological Triangulation

The data obtained from the narrative literature review, and the case analysis were integrated through methodological triangulation (Flick, 2009). This procedure enabled the confrontation of theoretical concepts with empirical evidence, strengthening the validity of the findings and highlighting convergences and contradictions across different contexts.

### 3.2. Justification of the Research Design

The decision to adopt a qualitative and narrative approach was intentional, as the aim was not to quantify effects but rather to interpret practices, meanings, and organisational resistances related to innovation in healthcare. Although the term *review* is used, this study does not follow formal systematic protocols such as PRISMA, but is guided by principles of narrative, reflexive, and critical rigour.

To ensure consistency, inclusion and exclusion criteria were made explicit, and transparent procedures were adopted for the selection and analysis of sources. In this way, the study aligns with recognised quality practices inspired by COREQ, even though it does not constitute a systematic review. Future research may adopt more formal methodologies (e.g., PRISMA or mixed-method protocols) to reinforce the robustness and replicability of the findings.

## 4. Presentation and Discussion of Results

Rehabilitation nursing has been significantly transformed by the advancement of digital technologies and the growing demand for personalised care. The literature reviewed reveals a broad consensus regarding the potential of technological innovation to optimise clinical outcomes, enhance organisational efficiency, and respond to patients' needs with greater precision (Leite et al., 2024; Mauro et al., 2024; Wong, Leung & Wang, 2020). Technologies such as artificial intelligence (AI), robotics, and telemedicine have proven to be essential tools for tailoring care, particularly for populations with specific needs, such as patients with visual impairment, neurological injuries, or complex chronic conditions (Maciejasz et al., 2014).

The authors' critical analysis, however, highlights tensions and divergences. On the one hand, there is an optimistic discourse surrounding emerging technologies; on the other, structural, cultural, and ethical barriers to their implementation persist. Kwak and Lee (2022) emphasise the importance of addressing organisational resistance and professional culture as tangible obstacles to change, echoing Mintzberg's (1979) classic analysis of organisational structures in highly professionalised contexts.

A central contribution of this study lies in valuing not only international institutional practices (e.g., Mayo Clinic, Cleveland Clinic) but also national experiences, such as *GerenciaDOR* — a digital tool developed in Portugal for the personalised management of chronic pain — and the innovation projects promoted by ANI and TecCare at the University of Coimbra. These experiences reveal that, although much of the discourse on technological innovation is imported from Anglo-Saxon contexts, there exists a local innovation capacity with high potential for scalability.

The analysis of the literature demonstrates convergence regarding the transformative potential of artificial intelligence and telemedicine, widely praised by authors such as Topol (2019), who underlines their disruptive impact on clinical practice. Nonetheless, significant contradictions also emerge, as other scholars, including Morley et al. (2020), warn of ethical risks and the insufficient institutional maturity for adopting such technologies. This tension between optimistic and critical perspectives underscores the need to analyse health innovation contextually and in a balanced way, avoiding both uncritical adherence and premature rejection. While authors such as Topol (2019) and Wong, Leung & Wang (2020) stress their transformative potential, others, including Morley et al. (2020) and Jobin et al. (2019), raise concerns about ethical issues, privacy risks, and institutional readiness. This duality highlights that innovation must be understood as a multifaceted phenomenon, where opportunities coexist with limitations, requiring a balance between technological enthusiasm and critical prudence.



At an operational level, technologies such as virtual reality (VR) and tele-rehabilitation systems, such as KiReS, have been successfully applied in neurological rehabilitation, enabling more motivating and effective interventions. Studies such as those by Chheang et al. (2023) and Idoko et al. (2024) document the benefits of these technologies in improving functional recovery and treatment adherence. The triangulation of data suggests that such solutions, when integrated with patient-centred practices and supported by appropriate ethical and training frameworks, contribute to more efficient and humanised rehabilitation.

Nevertheless, multiple challenges remain. Johnson and Martinez (2024) and Adler-Milstein and Huckman (2013) identify resistance to change, adoption costs, and a lack of professional training as major obstacles. The literature consistently indicates that innovation will only have a sustainable impact if accompanied by strategies for continuous capacity-building (Gajarawala & Pelkowski, 2021; Booth et al., 2021) and financial planning that supports infrastructure upgrades. In Portugal, many institutions within the National Health Service (SNS) face budgetary and technological constraints that hinder the adoption and review of such innovations, reinforcing the need for public policies to foster digital transformation.

Ethical issues emerge as a transversal axis of the analysis. Morley et al. (2020) and Jobin, Ienca, and Vayena (2019) warn of the risks associated with data privacy, the potential dehumanisation of care, and the lack of regulation adapted to new technological realities. These concerns must be addressed from the planning stages of innovations, not only at the implementation phase, requiring the establishment of multidisciplinary ethics committees and the adoption of international frameworks such as COREQ.

The case study analysis underscored the role of institutional leadership in promoting innovation. The Mayo Clinic, for instance, has invested heavily in AI for early diagnosis and remote monitoring, while the Cleveland Clinic prioritises data interoperability and surgical robotics. These experiences demonstrate that technology alone is insufficient: it is the organisational culture — grounded in continuous learning, participatory management, and openness to experimentation — that determines the success of innovations (Cosgrove, 2014; Furst, 2024).

Finally, it is essential to highlight the importance of aligning technological innovation with the principles of humanised care. Automation and data analysis should free up professionals' time to strengthen their relational presence with patients, as advocated by Mauro et al. (2024). In this sense, innovation becomes not only a technical tool but also an ethical and existential one, enabling care to become closer, more empathetic, and more effective. Beyond international experiences, it is crucial to acknowledge the concrete contributions developed within Portugal, which reinforce the local potential for significant clinical innovation.

#### **4.1. National Experiences of Innovation in Nursing: The Case of the ESEnFC**

In addition to international experiences, it is crucial to recognise the contributions developed within Portugal, which demonstrate the potential of the Portuguese ecosystem to generate clinically innovative solutions grounded in scientific evidence. Prominent in this scenario is the *Escola Superior de Enfermagem de Coimbra* (ESEnFC), which, through the *Health Sciences Research Unit: Nursing* (UICISA: E) and its innovation hub *TecCare*, has led highly relevant projects, supported by the National Innovation Agency (ANI) (UICISA: E, 2024; ANI, 2022).

Among these projects, the *Subcutaneous Hydration Device* (DHS) stands out, designed for palliative and home care. Its development followed principles of scientific prototyping and clinical usability assessment (Silva, Fernandes & Sousa, 2023). The device was tested in real-life contexts and has been cited as good practice in applied co-innovation (Martins et al., 2024). Such initiatives show that the Portuguese higher education system in nursing can produce innovative solutions anchored in the real needs of patients and professionals (Moura et al., 2023).

A central figure in this movement is Professor Pedro Parreira, whose leadership of the *Entrepreneurship Office* and the *TecCare* strategic axis has been decisive in consolidating the ESEnFC as a hub of health innovation. Parreira articulates academic entrepreneurship with applied research in technologies for rehabilitation nursing care, with both national and international impact. Projects such as *DigiNurse*, focused on developing digital



competences among students and professionals (Parreira, Santos-Costa & Graveto, 2021), and smart textiles for the prevention of pressure ulcers (Salgueiro-Oliveira, Parreira & Martins, 2023), exemplify this integrated, evidence-based approach.

The scientific output from these initiatives has been published in journals such as *Computers, Informatics, Nursing, Jerhub* and *Heliyon*, academically validating the ESEnC’s contributions to health innovation. Recent studies also highlight the importance of digital literacy and interoperability in sustaining technological adoption in clinical practice (Gonçalves, Parreira & Salgueiro-Oliveira, 2022).

These experiences reinforce that innovation goes beyond device development: it encompasses knowledge management, organisational sustainability, and the enhancement of nursing practice within the Portuguese context. Therefore, the inclusion of national examples in academic analyses of this nature is not only relevant but essential to support contextually adapted proposals and encourage innovative practices aligned with local realities.

The following table provides a comparative synthesis between international and Portuguese practices in technological innovation in rehabilitation nursing, identifying points of convergence and singularity in each context.

**Table 3:** Comparative examples of technological innovation in rehabilitation nursing: international vs. Portuguese contexts.

Type of Innovation	International Example	National Example (Portugal)	Expected Impact
AI in Diagnosis	Mayo Clinic: AI for fall screening and remote monitoring	ESEnC/TecCare: Prototyping of AI-based systems for home care	Enhanced safety and continuous clinical surveillance
Tele-Rehabilitation	KiReS System — Spain	<i>GerenciaDOR</i> project — Portugal (digital management of chronic pain)	Reduced travel; improved treatment adherence
Robotics	Cleveland Clinic: assisted and surgical robots	In the embryonic stage, under development in university centres	Potential for complex motor rehabilitation
Assistive Devices	Idoko et al. (2024): sensors for motor training	DHS — Subcutaneous Hydration Device (ESEnC/UICISA: E)	More effective palliative care
Innovation Management	Participatory culture (Cosgrove, 2014)	Hybrid ESEnC/ANI models involving clinical and academic collaboration	Sustainability and institutional replicability
Digital Capacity-Building	WHO and European Union — digital health literacy	<i>DigiNurse</i> — digital skills training in nursing (Parreira et al., 2021)	Strengthening digital competences
Smart Textiles	USA/Japan: wearables for vital signs	Smart textiles for pressure ulcer prevention (Salgueiro-Oliveira et al., 2023)	Injury prevention; improved clinical monitoring

**Source:** Author’s elaboration, based on Cosgrove (2014), Mauro et al. (2024), Chheang et al. (2023), Furst (2024), Idoko et al. (2024), Moura et al. (2023), Parreira et al. (2021), Salgueiro-Oliveira et al. (2023), Gonçalves et al. (2022), UICISA:E (2024).

The comparative analysis presented in Table 3 demonstrates that technological innovation in rehabilitation nursing is not confined to major international centres but finds meaningful expression in Portugal. The practices



of the ESEnC reveal that academic entrepreneurship, when aligned with scientific research and inter-institutional collaboration, can generate solutions with tangible and measurable impact. This finding reinforces the need to view the national context as an active agent in knowledge production and in the transformation of healthcare.

#### 4.2. Critical Discussion

The analysis developed in this article shows that the challenges of technological innovation in rehabilitation nursing are transversal yet assume specific nuances depending on organisational and cultural contexts. In the United States and Japan, digital maturity is more advanced, characterised by the consolidated integration of artificial intelligence and robotics (Christensen, Grossman & Hwang, 2009; Furst, 2024). In countries such as Portugal, while infrastructural constraints and limited investment persist, the active role of academic institutions in generating applied and contextualised innovation is particularly noteworthy (Parreira, Santos-Costa & Graveto, 2021).

The case of the *Escola Superior de Enfermagem de Coimbra* (ESEnC) is exemplary in this regard. Projects such as *DigiNurse*, the *Subcutaneous Hydration Device* (DHS), and smart textiles for the prevention of pressure ulcers have not only resulted in clinical prototypes but have also been validated in international publications, demonstrating the capacity of the Portuguese academic ecosystem to produce evidence-based and relevant solutions (Salgueiro-Oliveira, Parreira & Martins, 2023; Gonçalves, Parreira & Salgueiro-Oliveira, 2022). The articulation between research, clinical practice, and strategic management constitutes a distinguishing feature that can inspire hybrid models of innovation in other regions, bridging science, education, and care.

Despite these advances, the generalisation of such practices faces obstacles such as fragmented funding policies, disparities in professionals' digital literacy, and the absence of interoperable systems. The literature further warns of the risk of innovation becoming overly focused on technical performance to the detriment of humanised care (Guarducci et al., 2025). Striking a balance between technological efficiency and relational dimensions is particularly crucial in rehabilitation nursing, where the therapeutic relationship is an essential component of the recovery process (Moura et al., 2023).

Finally, it is important to acknowledge the methodological limitations of this study. As a narrative literature review, its purpose is not exhaustiveness but rather the construction of an integrated and critical analysis. This approach has enabled the mapping of trends, the identification of transformative experiences, and the proposal of theoretical-practical pathways for reflection. Future research should adopt mixed methodologies — incorporating interviews with professionals, focus groups, and clinical and organisational impact analyses — as well as broader international comparisons, to validate and consolidate sustainable models of innovation in rehabilitation nursing.

#### Conclusion

This study investigated the challenges and opportunities of technological innovation in rehabilitation nursing, integrating international literature and national experiences, with particular emphasis on the projects of the *Escola Superior de Enfermagem de Coimbra* (ESEnC), in partnership with the ANI and UICISA: E. The original contributions of this work are centred on three dimensions: (i) the systematic identification of facilitators and barriers — cultural, organisational, and infrastructural — that shape technological innovation in rehabilitation; (ii) the valorisation of validated national examples, such as *DigiNurse*, the *Subcutaneous Hydration Device* (DHS), and smart textiles for the prevention of pressure ulcers, which demonstrate Portugal's capacity to generate applicable and contextualised solutions; and (iii) the defence of hybrid models that combine technological innovation, strategic management, and humanisation as an essential condition for sustainable, person-centred practices.

The analysis highlighted convergences in the literature regarding the potential of artificial intelligence, tele-rehabilitation, and assistive devices to personalise care and optimise resources, while also underlining divergences in institutional levels of technological maturity and the ethical implications associated with their use.



Such differences reinforce the importance of critical approaches that consider specific organisational, pedagogical, and cultural contexts.

The limitations of this study include the exploratory and narrative nature of the review, the absence of quantitative empirical data, and the restricted timeframe (2020–2025). Nevertheless, the analysis enabled the mapping of trends, convergences, and contradictions, providing a solid basis for both theoretical and practical reflection. Future research should adopt mixed methodologies — such as interviews, focus groups, and clinical and organisational impact studies — and align with frameworks such as COREQ, to strengthen the robustness and replicability of the findings.

In summary, this study concludes that innovation in rehabilitation nursing should not be understood as a mere technological product, but rather as a cultural, pedagogical, and strategic process. The Portuguese experience, illustrated by the work of the ESEnC, demonstrates that academic entrepreneurship, when combined with transformational leadership and integrated management, can serve as a driving force for sustainable and humanised care transformation, making a significant contribution to nursing science, health management, and the modernisation of care systems in Portugal and on the global stage.

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### Ethical Statement

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