



# From Laboratory to Society: A Literature Analysis of Transforming Scientific Innovation into Real Technological Solutions

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## Abstract

The transformation of scientific innovation into real technological solutions remains a critical challenge in bridging the gap between research and societal impact. This study aims to analyze how innovation evolves from laboratory-based knowledge creation to societal adoption by addressing gaps in previous studies, particularly in integrating technology transfer, commercialization, and diffusion into a unified conceptual framework. The research identifies key stages in the innovation transformation process, including knowledge creation, technology transfer, research commercialization, and innovation diffusion, and examines how these stages interact within a broader innovation ecosystem. The findings reveal that innovation transformation follows a non-linear process characterized by iterative feedback loops between technology transfer, commercialization, and diffusion, with institutional support acting as a key moderating variable across all stages, including institutional support, policy frameworks, and digital transformation. Technology transfer and knowledge exchange serve as essential mechanisms that connect scientific research with industrial application, while commercialization enables the translation of innovations into market-ready solutions. Furthermore, innovation diffusion determines the extent to which these solutions are adopted and generate economic and social value. The study also highlights the growing role of digital technologies, particularly artificial intelligence, in accelerating innovation processes and enhancing collaboration across sectors. However, the effectiveness of these technologies depends on organizational readiness and ecosystem alignment. Overall, the research proposes a holistic perspective on innovation transformation, emphasizing the importance of integrating technological, institutional, and societal dimensions to achieve sustainable and impactful outcomes.

*Keywords:* Transfer, scientific innovation, knowledge transfer, research commercialization, innovation diffusion

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## 1. Introduction

The development of science and technology in recent decades has shown a significant increase in the production of scientific knowledge, but its contribution to real-world solutions in society still faces various structural limitations. Many research results end up in academic publications without being successfully transformed into impactful innovations. This phenomenon highlights the gap between research activities in the laboratory and their implementation in society, thus raising the need for new approaches capable of bridging this process systematically and sustainably.

In this context, the concept of transformative science has begun to develop as a new paradigm that emphasizes that science must be oriented towards solving real-world problems in society. This approach positions science as a tool for driving social change through directly implementable innovations, rather than merely as an academic activity isolated from social reality (Parodi et al., 2022).

In line with this, approaches such as real-world labs, technology assessment, and responsible research and innovation (RRI) have emerged as conceptual frameworks that seek to integrate the research process with societal needs. These three approaches emphasize the importance of multi-actor participation, experimentation in real-world contexts, and evaluation of the social and environmental impacts of technology. The integration of these three approaches yields reflexive sustainable technology labs, which allow innovations to be tested and developed directly within the social environment (Parodi et al., 2022).

Furthermore, the development of the concepts of living labs and transformative governance demonstrates that innovation transformation depends not only on technology but also on supportive policy and governance systems. Successfully implemented innovations are the result of complex interactions between academic, industrial,

government, and community actors, making an ecosystem-based approach crucial in ensuring the success of such transformations.

Furthermore, the literature on innovation policy emphasizes that the role of science, technology, and innovation is no longer limited to economic growth but is also directed at driving systemic change in society. This approach, known as transformative innovation policy, positions innovation as a key instrument in addressing global challenges such as sustainability and social inequality (Schot & Steinmueller, 2019).

Furthermore, studies on technology transfer and knowledge spillover demonstrate that the transfer of knowledge from research institutions to the industrial sector is a key stage in innovation transformation. However, this process often fails to run optimally due to a lack of collaboration and effective commercialization mechanisms, hindering the widespread use of research results (Scarrà & Piccaluga, 2022).

Furthermore, commercialization of research results is a major challenge in bridging the gap between science and practical application. Many academic institutions still face obstacles in developing an entrepreneurial orientation and managing market-based innovation, even though factors such as social networks and intellectual assets have been shown to play a crucial role in increasing commercialization success (Park et al., 2024).

In the digital era, this transformation is further accelerated by technological developments such as artificial intelligence and integrated digital systems. Digital technology not only accelerates the process of scientific discovery but also opens up new opportunities for developing innovation-based business models and production systems. However, this acceleration also poses new challenges related to the adoption and societal readiness to accept these technologies (Wang et al., 2023).

In addition to the transfer and commercialization processes, the success of innovation is also largely determined by the diffusion process within society. The diffusion of innovation theory explains that technology adoption is influenced by social, economic, and communication network factors. Therefore, developed innovations do not necessarily have an impact without widespread acceptance by end users (Guidolin & Manfredi, 2023).

Based on this description, it can be concluded that transforming scientific innovation into real technological solutions requires an integrated approach, involving cross-sector collaboration, and supported by a strong innovation ecosystem. Therefore, this study aims to comprehensively analyze how this process occurs, the factors influencing it, and develop a conceptual framework that can bridge the gap between scientific research and technology implementation in society.

## 2. Literature Review

The transformation of innovation from the laboratory to society has become a central issue in modern science, technology, and innovation studies. The transformative science approach emphasizes that scientific research must be oriented toward solving real-world problems, not simply producing knowledge. In this context, approaches such as real-world labs (RwLs) have developed as transdisciplinary experimental environments that connect scientists with communities to create practice-based solutions. RwLs enable the integration of knowledge production and social implementation through direct, real-world experiments, thereby accelerating the innovation transformation process (Parodi et al., 2022).

Furthermore, the concepts of responsible research and innovation (RRI) and technology assessment (TA) strengthen the role of science in society by emphasizing public participation, anticipating technological impacts, and responsiveness to social needs. The integration of RwLs, TA, and RRI results in a more reflective and adaptive approach to the innovation process, known as reflexive sustainable technology labs, which serve as a bridge between research and social implementation (Parodi et al., 2022).

In the policy realm, the concept of transformative innovation policy (TIP) marks a paradigm shift from innovation based on economic growth to innovation oriented toward systemic change and sustainability. This policy positions science, technology, and innovation as instruments for addressing global challenges such as climate change and social inequality, and emphasizes the importance of comprehensive socio-technical system transformation (Schot & Steinmueller, 2019). This approach is further reinforced by the concept of Society 5.0, which emphasizes the integration of digital technology with human needs to create more inclusive and sustainable social solutions (Fukuda, 2020).

In addition to policy factors, technology transfer and knowledge spillover processes play a crucial role in bridging the gap between research and implementation. Technology transfer enables knowledge generated in academic institutions to be utilized by the industrial sector, but its effectiveness depends heavily on a supportive innovation ecosystem. Studies show that without strong collaboration and efficient mechanisms, technology transfer often fails to generate tangible impact (Scarrà & Piccaluga, 2022). Furthermore, a collaborative approach across countries and sectors is key to increasing the effectiveness of innovation transfer, particularly in the context of sustainable development (Pandey et al., 2022).

In the organizational and industrial context, the adoption of research-derived technology is also influenced by a company's internal capacity and position within the global value chain. Research shows that technology transfer can enhance industrial competitiveness and drive improvements in the quality of innovation, particularly when supported by a resource-based strategy and integration within global value chains (Ren et al., 2023; Yan et al., 2024). This

suggests that innovation transformation depends not only on the technology itself, but also on the organization's readiness to adopt it.

Furthermore, the commercialization of research results is a critical stage in the innovation transformation process. Universities, as centers of knowledge production, play a crucial role in driving innovation through the formation of spin-offs and the development of science-based entrepreneurship. However, the success of commercialization is heavily influenced by non-technical factors such as intangible assets, social networks, and institutional support (Park et al., 2024; Huegel, 2024). Furthermore, the existence of Knowledge Transfer Offices (KTOs) is also crucial in facilitating interaction between academia and industry and enhancing the effectiveness of innovation services (Compagnucci & Spigarelli, 2024).

In the digital era, innovation transformation is being accelerated by technological developments such as artificial intelligence (AI) and integrated digital systems. AI not only increases efficiency in scientific discovery but also enables the exploration of complex patterns that were previously difficult to analyze. However, although these technologies accelerate the innovation process, challenges in implementation and adoption in society remain major issues (Wang et al., 2023). Furthermore, digitalization is also driving changes in business models and production systems across various industrial sectors (Brauner et al., 2022; Casciani et al., 2022).

In addition to technological and commercialization aspects, the process of innovation diffusion is a key factor in determining the success of technology implementation in society. The theory of innovation diffusion explains that technology adoption is influenced by social and economic factors, as well as communication networks. Therefore, innovations must be tailored to the end-user context to achieve widespread acceptance (Guidolin & Manfredi, 2023). Other studies have shown that knowledge transfer through patents and innovation policies also contributes to improving the quality of innovation at the regional level (Jin et al., 2022).

Furthermore, the literature also highlights the crucial role of innovation ecosystems involving various actors, including academia, industry, government, and the community. The triple helix model serves as an important framework for understanding these interactions, where cross-sector collaboration enables knowledge exchange and collectively strengthens innovation capacity. In this context, approaches such as living labs and social innovation are also crucial in ensuring that developed technologies are truly relevant to societal needs (Caro-Gonzalez et al., 2025).

Overall, the literature review demonstrates that the transformation of innovation from the laboratory to the community is a complex, multidimensional, and non-linear process. This process involves various stages, from knowledge creation and technology transfer to commercialization and the diffusion of innovation within society. Therefore, an integrated, ecosystem-based approach is needed to ensure that scientific research results can truly impact society.

### **3. Materials and Methods**

#### **3.1. Research Design**

This study uses a Systematic Literature Review (SLR) approach as the primary design for analyzing the transformation of innovation from the laboratory to society. This approach was chosen because it provides a comprehensive, structured, and transparent synthesis of the rapidly growing literature in the fields of technology transfer, scientific innovation, and research commercialization. SLRs enable researchers to systematically identify, evaluate, and integrate findings from multiple studies, resulting in a deeper understanding than conventional literature reviews.

Methodologically, SLRs aim to minimize bias through explicit and replicable procedures and enable the generalization of findings from multiple relevant studies. This approach is particularly important in innovation studies because topics such as technology transfer and innovation diffusion involve multiple, multidisciplinary perspectives and are highly complex. Therefore, the use of SLRs allows for the integration of various empirical and conceptual findings into a more holistic analytical framework.

This study adopts the SLR stages developed by Tranfield et al. (2003), which consist of three main phases: (1) planning the review, (2) conducting the review, and (3) reporting and dissemination. This stage ensures that the research process is conducted systematically, from formulating research questions to synthesizing the literature. In the planning stage, the research topic and scope are identified, focusing on the relationship between knowledge transfer, technology transfer, and innovation diffusion. Next, in the implementation stage, the literature search, selection, and evaluation are conducted based on specific criteria. The final stage includes analyzing and compiling the results into a conceptual framework.

Furthermore, this research design integrates a knowledge-based approach to understanding the technology transfer and research commercialization process. This perspective emphasizes that knowledge is a key strategic resource in creating competitive advantage and plays a crucial role in the innovation and diffusion processes of technology. Previous studies have shown that a knowledge-based approach can help identify key factors influencing the success of technology transfer, such as absorptive capacity, inter-organizational collaboration, and knowledge management mechanisms (Alkhazaleh et al., 2022).

Furthermore, this research design considers the inherently non-linear nature of the innovation transformation process, which is non-linear. The transformation from scientific research to technological implementation does not

occur directly but rather through various stages, such as knowledge transfer, commercialization, and innovation diffusion. Therefore, the SLR approach allows for the identification of patterns, relationships between variables, and research gaps that have not been widely explored in previous literature.

Therefore, the use of an SLR-based research design in this study aims not only to summarize the existing literature but also to develop a more integrated conceptual understanding of how scientific innovations can be transformed into tangible technological solutions that impact society.

### 3.2. Data Sources and Search Strategy

The data sources for this study were obtained from various reputable scientific databases that provide access to high-quality, peer-reviewed publications. The databases used included Google Scholar, Scopus, ScienceDirect, and SpringerLink. These databases were selected based on their broad multidisciplinary coverage, particularly in the fields of science, technology, innovation, and knowledge management, making them relevant to this research topic.

The literature search was conducted systematically using a combination of keywords designed to capture key concepts in the transformation of innovation from the laboratory to society. The primary keywords used included technology transfer, scientific innovation, knowledge transfer, research commercialization, and innovation diffusion. These keywords were chosen because they represent critical stages in the innovation process, from knowledge creation to technology adoption by society.

To improve the accuracy and relevance of search results, Boolean operators such as AND and OR were used to combine keywords. Examples of search strategies used include: "technology transfer AND innovation diffusion," "scientific innovation AND commercialization," and "knowledge transfer AND industry adoption." Using this combination allows researchers to identify literature that is not only thematically relevant but also encompasses the relationships between concepts within the innovation ecosystem.

Furthermore, the search process also considers variations in frequently used terminology in the literature, such as innovation ecosystem, technology commercialization, and knowledge diffusion, to broaden the scope of search results without compromising relevance. This strategy is important given the multidisciplinary nature of innovation-related literature and often uses different terms to describe similar concepts.

To ensure the quality of the literature used, the search focused on scientific journal articles published within a specific timeframe and making significant contributions to the research topic. This approach aligns with systematic literature review practices, which emphasize transparency, replicability, and validity in the literature identification process. Thus, the search strategy used in this study was able to produce a comprehensive, relevant, and representative body of literature for further analysis.

### 3.3. Inclusion and Exclusion Criteria

To ensure the quality and relevance of the literature analyzed, this study applied strict selection criteria in the article screening process. Inclusion criteria included peer-reviewed scientific journal articles indexed in reputable databases such as Scopus or other credible academic sources. Furthermore, the selected articles were published between 2018 and 2025 to ensure novelty and relevance to current developments in the field of innovation and technology transfer. Included studies must also explicitly address topics related to technology transfer, innovation diffusion, or research commercialization, and employ a clear methodological approach, both empirical and literature-based.

Conversely, exclusion criteria were applied to filter out literature that did not meet academic standards or research relevance. Non-scientific articles such as blogs, opinion pieces, popular reports, or documents without peer review were excluded from the analysis. Furthermore, studies not directly related to the transformation of innovation from the laboratory to society were eliminated to maintain the research's focus. The screening process also included the removal of duplicate articles emerging from various databases, ensuring that only unique and relevant literature was used in the subsequent stages of the analysis.

The application of these inclusion and exclusion criteria aims to increase the validity and reliability of the study results and ensure that the resulting literature synthesis truly represents the latest scientific developments in innovation, knowledge transfer, and research commercialization. Therefore, the results of this study are expected to have a strong evidence base and be academically accountable.

### 3.4. Data Extraction and Analysis

Articles that passed the selection stage were then analyzed using a qualitative content analysis approach to identify patterns, themes, and relationships between concepts in the literature. The analysis process began with identifying the main themes emerging from each study, followed by classification based on the focus of the study: technology transfer, knowledge transfer, research commercialization, and innovation diffusion. This stage allowed for a systematic grouping of the literature, facilitating an understanding of each study's contribution to the research topic.

Next, the findings from the various studies were synthesized to build a conceptual framework that illustrates the relationships between processes in innovation transformation. This approach is important because the technology

transfer process is not linear, but rather involves complex interactions between various factors such as policies, organizational structures, absorptive capacity, and collaboration between actors within the innovation ecosystem (Scarrà & Piccaluga, 2022). Therefore, the analysis focused not only on each concept separately but also on the dynamic interrelationships between these elements.

Furthermore, the analysis also considers the causal and functional relationships between concepts, particularly how knowledge transfer contributes to accelerating innovation diffusion and improving the quality of innovation at the industry and regional levels (Jin et al., 2022; Guidolin & Manfredi, 2023). With this approach, the research not only produces a literature synthesis but also identifies integrative patterns that can be used as a basis for developing a conceptual model of innovation transformation from the laboratory to society.

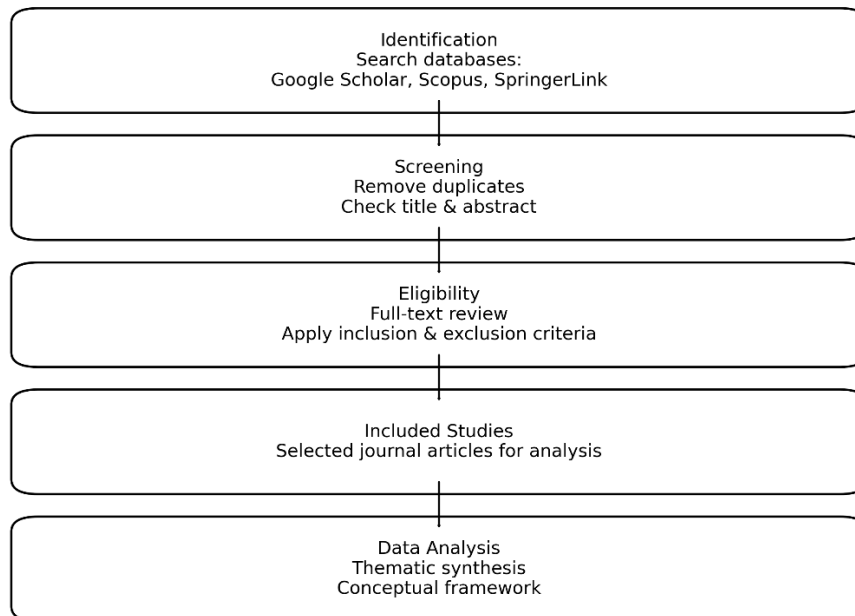
### 3.5. Research Flow Diagram

The research flow in this study follows the systematic stages commonly used in SLR, encompassing identification, screening, eligibility selection, and data analysis. In the identification stage, researchers conducted a literature search in various reputable scientific databases such as Google Scholar, Scopus, and SpringerLink using predetermined keywords. This stage aimed to collect as many articles as possible relevant to the research topic.

Next, the screening stage involved removing duplicate articles and conducting an initial review based on titles and abstracts. This process aimed to quickly filter out irrelevant literature before conducting a more in-depth evaluation. Afterward, in the eligibility stage, articles that passed the initial selection were read in their entirety (full-text review) and evaluated based on predetermined inclusion and exclusion criteria.

The next stage was the inclusion of studies, referring to a collection of articles that met all criteria and were deemed suitable for analysis. These articles then served as the basis for the data analysis process, which involved thematic synthesis and the development of a conceptual framework to understand the relationship between technology transfer, knowledge transfer, research commercialization, and innovation diffusion. This process was iterative and reflective, allowing for a more in-depth identification of patterns and interrelationships between concepts.

The complete flow of this research process is presented in Figure 1 to provide a visual representation of the systematic and structured stages.



**Figure 1:** research flow diagram based on a systematic literature review

#### 3.5.1. Structure

Research articles should be divided into the sections listed below. Principal sections should be numbered consecutively (1. Introduction, 2. Materials and methods, etc.) and subsections should be numbered 1.1., 1.2., etc. Do not number the Acknowledgements or References sections.

Manuscripts must be written in English. Contributors who are not native English speakers are strongly advised to ensure that a colleague fluent in the English language or a professional language editor has reviewed their manuscript. Concise English without jargon should be used. Repetitive use of long sentences and passive voice should be avoided. It is strongly recommended that the text be run through computer spelling and grammar programs. Either British or American spelling is acceptable but must be consistent throughout.

## 4. Results and Discussion

### 4.1. Transformative Innovation: From Knowledge Production to Societal Impact

The synthesis of the literature indicates that innovation transformation from laboratory to society is a multidimensional process involving interactions between technology, knowledge, policy, and social actors. To provide a structured overview, a mapping of the most representative and influential studies was conducted to capture the key stages of innovation transformation. The representative literature mapping is presented in Table 1.

**Table 1: Representative Literature Mapping of Innovation Transformation**

| Author                          | Focus Area                | Method         | Key Findings                                 | Category          |
|---------------------------------|---------------------------|----------------|--|-------------------|
| Schot & Steinmueller (2019)     | Transformative innovation | Conceptual     | Innovation as systemic change                | Policy            |
| Fukuda (2020)                   | Society 5.0               | Conceptual     | Integration of technology and society        | Ecosystem         |
| Parodi et al. (2022)            | Real-world labs           | Conceptual     | Societal-based innovation experiments        | Ecosystem         |
| Caro-Gonzalez et al. (2025)     | Living labs               | Empirical      | Governance in social innovation              | Policy            |
| Scarrà & Piccaluga (2022)       | Technology transfer       | Review         | Complexity of technology transfer            | Tech Transfer     |
| Alkhazaleh et al. (2022)        | Industry 4.0              | SLR            | Success factors of technology transfer       | Tech Transfer     |
| Compagnucci & Spigarelli (2024) | KTO                       | Conceptual     | Institutional role in knowledge transfer     | Knowledge         |
| Park et al. (2024)              | Spin-offs                 | Empirical      | Importance of intangible assets              | Commercialization |
| Naderi et al. (2023)            | Entrepreneurship          | Meta-synthesis | Commercialization as entrepreneurial process | Commercialization |
| Guidolin & Manfredi (2023)      | Diffusion theory          | Review         | Models of innovation diffusion               | Diffusion         |
| Jin et al. (2022)               | Patent transfer           | Empirical      | Diffusion improves innovation quality        | Diffusion         |
| Wang et al. (2023)              | AI in science             | Review         | AI accelerates scientific discovery          | Digital           |
| Brauner et al. (2022)           | Digital production        | Review         | Digital transformation in industry           | Digital           |
| Dutta et al. (2023)             | Global innovation         | Report         | Macro-level innovation drivers               | Policy            |

Table 1 illustrates that the selected literature can be categorized into several key domains representing the stages of innovation transformation, namely policy and ecosystem, technology transfer, knowledge transfer, research commercialization, innovation diffusion, and digital transformation. The selected studies serve as representative references that provide both conceptual and empirical insights into each domain.

The mapping highlights that transformative innovation and ecosystem-based approaches form the theoretical foundation for understanding how innovation evolves from knowledge creation to societal impact. Furthermore, technology transfer and knowledge transfer emerge as critical bridging mechanisms between research outputs and real-world application. Meanwhile, commercialization and innovation diffusion represent the final stages that determine whether innovations can generate tangible economic and social value.

In addition, the inclusion of digital transformation emphasizes the growing role of emerging technologies, particularly artificial intelligence and digital systems, in accelerating innovation processes across sectors. At the same time, the policy and ecosystem perspective underscores the importance of governance, institutional support, and macro-level conditions in enabling successful innovation transformation. Therefore, this literature mapping not only serves as a structured summary of key studies but also provides a conceptual foundation for the subsequent analysis of the relationships among the core components of innovation transformation discussed in the following sections.

### 4.2. Technology Transfer and Innovation Ecosystem

The synthesis of the literature highlights that technology transfer serves as a critical mechanism in bridging the gap between scientific research and real-world application. Rather than a simple linear process of knowledge movement, technology transfer is increasingly understood as a complex, systemic activity embedded within broader innovation ecosystems. It involves not only the transfer of technological artifacts and knowledge, but also processes of adaptation, integration, and co-development across institutional and industrial contexts (Scarrà & Piccaluga, 2022).

Within the innovation ecosystem perspective, the effectiveness of technology transfer is strongly influenced by the interaction between multiple actors, including universities, industries, governments, and intermediary institutions. The concept of transformative innovation emphasizes that such interactions must be aligned toward addressing societal challenges, requiring coordinated governance and policy support (Schot & Steinmueller, 2019). Similarly, the Society

5.0 framework underscores the need for a human-centered integration of technology within socio-economic systems, further reinforcing the role of ecosystems in shaping innovation outcomes (Fukuda, 2020).

Empirical evidence suggests that the success of technology transfer is closely linked to organizational capabilities and structural positioning within global value chains. Firms that are better integrated into global production networks tend to achieve higher levels of technological upgrading through effective transfer mechanisms (Yan et al., 2024). From a resource-based perspective, the adoption of transferred technologies can significantly enhance firm performance and support the transition toward sustainable and circular economy models (Ren et al., 2023). Additionally, contextual factors such as geographic location and asset value have been found to moderate the relationship between technology transfer and organizational competitiveness (Rambe & Khaola, 2023).

However, significant challenges remain, particularly within academic institutions. Studies indicate that universities often face inefficiencies in technology transfer processes due to fragmented structures, limited industry collaboration, and inadequate institutional support (Ma et al., 2022). This highlights the importance of strengthening internal mechanisms and fostering external partnerships to improve transfer outcomes. The role of Knowledge Transfer Offices (KTOs) becomes essential in this context, as they facilitate the commercialization and dissemination of research outputs through structured knowledge exchange processes (Compagnucci & Spigarelli, 2024).

Furthermore, the evolution of Industry 4.0 has reshaped the landscape of technology transfer by introducing digital infrastructures and data-driven systems. A systematic review by Alkhazaleh et al. (2022) identifies key success factors in this era, including digital readiness, organizational flexibility, and collaborative networks. In parallel, cross-border innovation cooperation is increasingly recognized as a crucial driver for sustainable development, particularly in developing countries where knowledge and technology gaps remain significant (Pandey et al., 2022).

In addition, experimental approaches such as real-world labs and living labs demonstrate that technology transfer can be more effective when embedded in participatory and context-driven environments. These approaches enable continuous feedback between technology developers and end-users, thereby enhancing the relevance and applicability of innovations (Parodi et al., 2022; Caro-Gonzalez et al., 2025). The findings suggest that technology transfer should not be viewed as an isolated process, but as an integral component of a dynamic innovation ecosystem. Its success depends on the alignment of technological capabilities, institutional frameworks, policy support, and collaborative networks. Therefore, strengthening innovation ecosystems is essential to ensure that scientific discoveries can be effectively translated into technological solutions that generate meaningful societal impact.

### **4.3. Knowledge Transfer and Institutional Support**

The literature synthesis indicates that knowledge transfer plays a fundamental role in accelerating innovation by enabling the flow of ideas, expertise, and capabilities across organizational and institutional boundaries. Unlike technology transfer, which often focuses on tangible outputs, knowledge transfer emphasizes the dissemination of tacit and explicit knowledge that underpins innovation processes. This transfer is essential for enhancing learning, improving problem-solving capacity, and fostering continuous innovation across sectors.

Institutional support emerges as a critical enabler in facilitating effective knowledge transfer. In particular, intermediary structures such as Knowledge Transfer Offices (KTOs) play a strategic role in bridging academia and industry by managing intellectual assets, supporting collaboration, and facilitating the commercialization of research outputs (Compagnucci & Spigarelli, 2024). These institutions help formalize knowledge exchange processes, reduce barriers to collaboration, and ensure that research findings are translated into practical applications.

Furthermore, empirical evidence suggests that knowledge transfer contributes significantly to improving innovation quality and regional development. Mechanisms such as knowledge spillovers and patent dissemination allow innovations to spread beyond their origin, enhancing technological capabilities across industries and regions (Jin et al., 2022). This highlights the importance of building strong knowledge networks and fostering collaboration among stakeholders to maximize the impact of innovation.

However, the effectiveness of knowledge transfer is highly dependent on contextual factors, including organizational culture, absorptive capacity, and the availability of supportive infrastructure. Without adequate institutional frameworks and collaboration mechanisms, knowledge transfer processes may become fragmented and inefficient. Therefore, strengthening institutional capacity and promoting knowledge-sharing cultures are essential to ensure that knowledge generated in research environments can be effectively utilized in real-world applications. The findings emphasize that knowledge transfer is not merely a supporting activity but a core component of the innovation ecosystem. Its success relies on the integration of institutional support, collaborative networks, and enabling environments that facilitate the continuous exchange and application of knowledge across different domains.

### **4.4. Research Commercialization and Entrepreneurial Dynamics**

Research commercialization represents a critical phase in transforming scientific knowledge into marketable innovations, where intangible assets such as intellectual property, human capital, and organizational capabilities play a decisive role in determining success (Park et al., 2024). These findings indicate that commercialization is not merely a technical extension of research, but a strategic process that requires the effective management of non-physical resources within an innovation ecosystem.

The role of social capital further strengthens this process, as networks, trust, and collaboration significantly influence both research performance and commercialization outcomes (Huegel, 2024). In this context, strong relational ties between academia, industry, and other stakeholders enable access to funding, expertise, and market opportunities, thereby accelerating the transition from laboratory research to real-world application.

Commercialization capability also emerges as a key determinant, encompassing dimensions such as strategic alignment, institutional readiness, and market orientation (Tikas, 2025). However, many academic institutions still face structural and cultural barriers, including limited entrepreneurial mindset, insufficient incentives, and weak industry engagement, which hinder the effective translation of research outputs into commercial products (Suhaimi et al., 2022).

From an entrepreneurial perspective, commercialization is increasingly viewed as an integrated process within the broader university innovation system, where knowledge creation, technology development, and market application are interconnected (Naderi et al., 2023). This perspective redefines the role of universities as not only knowledge producers but also active contributors to economic and societal development.

A concrete illustration of this transformation can be observed in the successful commercialization of advanced supercapacitor materials, where laboratory research is systematically scaled and optimized into practical applications (Huang et al., 2023). This example highlights that effective commercialization requires a combination of scientific excellence, engineering capability, and market-driven strategies, reinforcing its role as a crucial bridge between innovation and societal impact.

#### **4.5. Digital Transformation and Artificial Intelligence**

Digital transformation has emerged as a key driver in accelerating innovation processes, particularly through the integration of advanced technologies such as artificial intelligence (AI) and data-driven systems. The increasing availability of computational power and large-scale data has enabled more efficient analysis, prediction, and optimization across various domains. In this context, digital technologies are not only supporting innovation but also reshaping how knowledge is created, processed, and applied within scientific and industrial environments (Wang et al., 2023).

The role of AI is particularly significant in enhancing research productivity and enabling new forms of scientific discovery. AI-driven approaches allow researchers to explore complex datasets, identify hidden patterns, and generate insights that would be difficult to achieve through conventional methods. In the academic sector, digital transformation has also led to the development of intelligent systems that improve educational services and knowledge dissemination, thereby strengthening the link between research and application (Okunlaya et al., 2022).

In industrial contexts, digital transformation has fundamentally altered production systems and organizational structures by introducing automation, connectivity, and real-time data integration (Brauner et al., 2022). These changes enable more flexible and efficient production processes, while also supporting innovation in business models and operational strategies. For instance, industries such as fashion have leveraged digital technologies to enhance supply chain transparency, sustainability, and customer engagement, demonstrating that digital transformation extends beyond technical improvements to include broader organizational and strategic innovation (Casciani et al., 2022).

However, the impact of digital transformation on innovation outcomes is not automatic and depends heavily on the level of technology adoption and diffusion within organizations. Empirical evidence suggests that digitalization contributes to innovation performance only when it is effectively integrated into organizational processes and supported by adequate capabilities and infrastructure (Hassan et al., 2024). This highlights the importance of aligning technological investments with organizational readiness and strategic objectives.

Overall, digital transformation and AI function as critical enablers within the innovation ecosystem, enhancing the speed, scale, and scope of innovation processes. Their successful implementation depends not only on technological advancement but also on the ability of organizations and institutions to adapt, collaborate, and effectively utilize digital resources to generate meaningful and sustainable innovation outcomes.

#### **4.6. Innovation Diffusion and Societal Adoption**

Innovation diffusion represents the final stage in the transformation of scientific knowledge into societal impact, where technologies and ideas are adopted and utilized by end users. This process is inherently complex and influenced by multiple factors, including communication channels, social networks, economic conditions, and institutional environments. Theoretical models emphasize that diffusion does not occur simultaneously across all users, but rather follows a gradual pattern shaped by varying levels of readiness and acceptance (Guidolin & Manfredi, 2023).

The effectiveness of innovation diffusion is closely linked to prior stages such as technology transfer and knowledge dissemination. Empirical evidence shows that mechanisms like patent transfer and knowledge spillovers significantly enhance innovation quality and regional development by enabling wider access to technological advancements (Jin et al., 2022). This indicates that diffusion is not merely a passive outcome, but an active process that amplifies the impact of innovation across different sectors and regions.

In the context of public sector innovation, diffusion is also shaped by policy implementation and local adaptation. Case studies demonstrate that the successful adoption of innovation often depends on how well it is aligned with local needs, governance structures, and user capabilities (Handrian et al., 2024). This highlights the importance of contextualizing innovation to ensure its relevance and sustainability within specific societal settings.

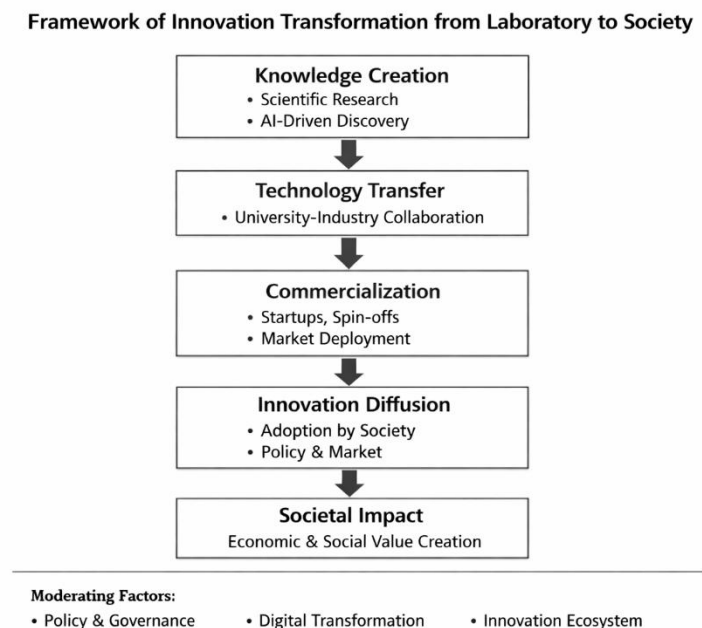
Moreover, digital transformation has further accelerated diffusion processes by enabling faster communication, broader access to information, and increased connectivity among users. However, the benefits of digitalization depend on the extent to which technologies are effectively adopted and integrated within organizations and communities. Without sufficient digital readiness and support, the diffusion process may remain limited despite the availability of advanced technologies. The findings suggest that innovation diffusion is a critical determinant of whether scientific and technological advancements can generate meaningful societal impact. Its success depends on the interaction between technological readiness, social acceptance, policy support, and institutional capacity, reinforcing the need for a holistic approach in managing innovation ecosystems.

#### Integrated Discussion: Toward a Holistic Innovation Framework

The overall findings of this study indicate that innovation transformation from laboratory to society is not a linear process, but rather a dynamic and interconnected system involving multiple stages and actors. The synthesis of the literature reveals four core components that shape this transformation, namely knowledge creation, technology transfer, research commercialization, and innovation diffusion. These components are interdependent and collectively determine the extent to which scientific discoveries can generate tangible societal impact.

Furthermore, the analysis highlights that the effectiveness of this transformation process is strongly influenced by enabling factors such as digital transformation, institutional support, and policy frameworks. The emergence of artificial intelligence and digital technologies has accelerated knowledge production and innovation processes (Wang et al., 2023; Brauner et al., 2022), while institutional mechanisms such as knowledge transfer offices and innovation governance structures facilitate the movement of knowledge and technology across sectors (Compagnucci & Spigarelli, 2024; Caro-Gonzalez et al., 2025). At the macro level, policy and ecosystem readiness remain critical in shaping innovation performance and diffusion capacity (Dutta et al., 2023; Schot & Steinmueller, 2019).

To synthesize these findings, a conceptual framework is proposed to illustrate the holistic process of innovation transformation, as shown in Figure 2.



**Figure 2:** conceptual framework of innovation transformation from laboratory to society

Figure 2 illustrates that innovation transformation follows a sequential yet iterative pathway, beginning with knowledge creation and culminating in societal impact. Each stage is interconnected, where outputs from one phase become inputs for the next. However, the process is not strictly linear, as feedback loops may occur, particularly when societal needs influence future research directions.

The framework also emphasizes the role of moderating factors, including policy, digital transformation, and innovation ecosystems, which influence the efficiency and effectiveness of each stage. These factors act as enablers that can either accelerate or constrain the movement of innovation across the system. For instance, strong policy support and institutional readiness can enhance technology transfer and commercialization, while digital transformation can significantly speed up knowledge dissemination and innovation diffusion.

Overall, this integrated framework provides a comprehensive understanding of how scientific innovation can be transformed into real technological solutions that benefit society. It highlights the importance of a holistic approach

that aligns technological capabilities, institutional mechanisms, and policy environments to ensure sustainable and impactful innovation outcomes.

## 5. Conclusion

This study has systematically examined the process of transforming scientific innovation into real technological solutions through a structured literature review approach. By analyzing a wide range of scholarly works, the research identifies that innovation transformation is not a linear progression, but a complex and interconnected system involving multiple stages, including knowledge creation, technology transfer, research commercialization, and innovation diffusion. Each of these stages plays a critical role in ensuring that scientific discoveries can move beyond the laboratory and generate meaningful societal impact.

The findings reveal that the success of this transformation process is highly dependent on the interaction between technological capabilities, institutional support, and policy frameworks. Technology transfer and knowledge transfer emerge as key bridging mechanisms that connect research outputs with industrial applications, while commercialization acts as a critical phase in converting innovations into market-ready solutions. Furthermore, innovation diffusion determines the extent to which these solutions are adopted and utilized within society, ultimately shaping their economic and social value.

In addition, the study highlights the growing importance of digital transformation and artificial intelligence as enabling factors that accelerate innovation processes across all stages. These technologies enhance the efficiency of knowledge creation, facilitate collaboration, and expand the reach of innovation diffusion. However, their effectiveness is contingent upon organizational readiness, infrastructure, and the broader innovation ecosystem.

Overall, this research concludes that achieving successful innovation transformation requires a holistic approach that integrates scientific research, institutional mechanisms, and socio-economic contexts. The proposed framework emphasizes that innovation should be viewed as an ecosystem-driven process, where collaboration among stakeholders and alignment of policies play a decisive role in translating scientific knowledge into impactful technological solutions for society.

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