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PARTICIPATORY AGRICULTURAL INNOVATION THROUGH LIVING LABS: AN INSTITUTIONAL FRAMEWORK FOR RENEWING AGRICULTURAL EXTENSION

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ABSTRACT

This paper examines living labs as an innovative approach for restructuring agricultural extension systems and enhancing the effectiveness of agricultural knowledge and innovation systems in response to contemporary environmental, economic, and social challenges. It aims to develop an integrated operational model that repositions agricultural extension at the core of the living lab ecosystem, redefining it as an institutional driver and innovation intermediary leading participatory innovation processes within rural communities. The study adopts a conceptual–analytical approach through a critical review of specialized literature and an examination of the conceptual and practical gaps in applying living labs in agricultural contexts, particularly the limited attention given to the institutional leadership role of agricultural extension. Based on this analysis, the paper proposes the Participatory Agricultural Innovation through Living Labs Model (PAI-LLM), which consists of seven interrelated components: contextual inputs, the institutional core represented by agricultural extension, the operational platform (agricultural living lab), governance and coordination mechanisms, transformational processes, developmental outputs, and sustainability mechanisms. The findings indicate that the proposed model provides a practical framework for transforming living labs from limited experimental initiatives into a sustainable institutional operating mechanism capable of maximizing the efficiency of scarce human resources in agricultural extension, especially in light of the sharp decline in the number of extension agents in Egypt. The model further demonstrates the potential of extension-led living labs to enhance participatory learning, accelerate the adoption of agricultural innovations, strengthen the resilience of production systems, and promote more inclusive and sustainable rural development. The paper concludes that adopting the PAI-LLM represents a realistic strategic option for renewing agricultural extension systems in

developing countries and supports the formulation of more responsive agricultural policies, while opening future research avenues to assess the long-term impact of living labs on food security and rural development.

KEYWORDS: Living Labs, Agricultural Extension, Participatory Innovation, AKIS (Agricultural Knowledge and Innovation Systems), Agricultural Sustainability, Agricultural Systems Resilience, Rural Development.

1. INTRODUCTION

The contemporary agricultural sector is undergoing profound structural transformations driven by escalating challenges related to climate change, food security pressures, and the increasing complexity of supply chains. These factors necessitate a shift toward more open, participatory, and sustainable innovation models. In this context, Living Labs have emerged as one of the most effective frameworks for integrating scientific research with field application in real-life settings, through the active involvement of users and multiple stakeholders in the co-design, development, and iterative testing of solutions (Greve et al., 2021; Borda et al., 2024).

Living Labs are defined as participatory innovation platforms operating in real-life contexts and managed through partnerships among the public sector, the private sector, and society. This arrangement enables the generation of applied knowledge, the validation of technical and social solutions under actual conditions of use, and the acceleration of innovation adoption (Greve et al., 2021). This model has evolved from a marginal innovation practice into a core component of modern innovation management, particularly in sectors characterized by intertwined technical, economic, and social dimensions, such as agriculture and food systems. In the agricultural domain in particular, the concept of Agro Living Labs has emerged as a direct response to the environmental, economic, and social crises facing agricultural and food systems. These labs aim to support the transition toward sustainable, resilient, and socially inclusive food systems by stimulating open innovation and strengthening collaboration among farmers, researchers, policymakers, and the private sector (Trivellas et al., 2023). The literature highlights that this approach enables the formation of cross-sectoral community alliances and contributes to the development of context-adapted solutions, in line with the requirements of contemporary Agricultural Knowledge and Innovation Systems.

Several studies also emphasize that living labs play the role of innovation intermediaries within knowledge systems by coordinating interactions among diverse actors, translating real-world needs into applicable solutions, and fostering experimental and participatory learning (Shvetsova & Lee, 2021). This function is particularly important in agricultural extension, where the role of extension is no longer limited to knowledge transfer but has evolved into a central actor in organizing innovation processes, building capacities, and enabling farmers' active engagement with technology and knowledge.

In light of these transformations, there is a growing need to redefine the roles of agricultural extension within more integrated and flexible innovation models, viewing it as a structural component of living lab systems that contributes to linking scientific knowledge with production realities, supporting experiential learning and community participation, and facilitating the transition toward more sustainable and resilient agricultural systems (Rogers et al., 2023; Borda et al., 2024).

Within this framework, this paper seeks to analyze the role of living labs in advancing agricultural extension and strengthening agricultural knowledge and innovation systems, while highlighting their developmental and practical impacts in supporting sustainability, resilience, and capacity building within agricultural communities, in light of recent scientific literature that has emphasized the growing shift toward this model as a fundamental pillar of contemporary agricultural innovation (Greve et al., 2021; Trivellas et al., 2023).

1.1. Conceptual and Theoretical Framework of Living Labs

In contemporary literature, living labs are presented as multi-actor participatory innovation systems based on the engagement of diverse stakeholders, including governmental institutions, the private sector, universities, civil society, and end users, in joint processes of knowledge generation, solution design, and testing within real-life contexts. This participatory nature reflects a shift in innovation from closed development models toward open, collaboration-based models, thereby enhancing the quality of solutions and their alignment with actual societal needs (Greve et al., 2021; Borda et al., 2024).

The literature also indicates that living labs play the role of innovation intermediaries within innovation systems, functioning as a link between the production of scientific knowledge on the one hand and the requirements of practical application on the other. In this regard, living labs provide organizational and structural platforms that facilitate interaction among different actors, support participatory learning processes, and accelerate the transfer of ideas from the laboratory to the field and from theory to practice. Greve et al. (2021) highlighted that living labs have become an effective intermediary structure that bridges the traditional gap between research and development and the market, contributing to enhanced integration between knowledge and application in complex and

dynamic environments.

Within the context of global transitions toward sustainability, the role of living labs emerges as a key driver of the shift toward sustainable and resilient innovation. They enable the testing of technical, organizational, and social solutions under real-world conditions while simultaneously considering environmental, economic, and social dimensions. Studies confirm that living labs represent strategic tools for supporting communities and institutions in building systems that are more capable of adapting to crises and shocks and in enhancing well-being and quality of life through open innovation and broad community participation (Trivellas et al., 2023; Borda et al., 2024). Experiences of living labs in agricultural and food systems further demonstrate that this model contributes to building the resilience of production systems, achieving social inclusion, and supporting the transition toward more sustainable development pathways (Trivellas et al., 2023). Accordingly, living labs are theoretically grounded at the intersection of three interrelated dimensions: multi-actor participatory innovation, innovation intermediation between knowledge and application, and support for the transition toward sustainable and resilient innovation patterns. Together, these dimensions constitute the conceptual framework underpinning this study's analysis of the role of living labs within agricultural extension systems and Agricultural Knowledge and Innovation Systems.

1.2. Living Labs and Agricultural Knowledge and Innovation Systems

Agricultural Knowledge and Innovation Systems (AKIS) are undergoing a qualitative transformation in both their structure and functions, as linear channels of knowledge transfer from researchers to farmers are no longer sufficient to address the complexity of contemporary environmental, economic, and social challenges. In this context, living labs emerge as an advanced integrative framework that restruct0ures relationships among actors within the AKIS by shifting from a "knowledge transfer" logic to a "co-creation of knowledge" logic based on interaction and experimentation in real-life settings (Potters et al., 2022).

The literature emphasizes that living labs contribute to enhancing the effectiveness of agricultural innovation systems by building participatory learning networks that bring together farmers, researchers, agricultural extension agents, the private sector, and policymakers. This configuration facilitates the exchange of experiences and tacit knowledge and transforms them into implementable, practice-oriented solutions. Accordingly, this model is viewed as a strategic mechanism for strengthening linkages between scientific knowledge and field practice, thereby addressing one of the most persistent shortcomings of traditional agricultural extension systems (Potters et al., 2022; Schuurman et al., 2016).

Living labs also play a central role in supporting the transition toward sustainable and resilient agricultural and food systems, as they enable the testing of technical, organizational, and social innovations under actual conditions of use while simultaneously considering environmental, social, and economic dimensions. Recent studies show that this form of participatory innovation empowers agricultural communities to build adaptive capacities to climatic and economic shocks, enhances their ability to manage risks, and maximizes the use of local resources (Herth et al., 2024; Filho et al., 2023). Within this same framework, living labs contribute to redefining the position of agricultural extension within the AKIS, as the extension agent shifts from a mere transmitter of information to a coordinator of co-innovation processes, a facilitator of experiential learning, and an intermediary between scientific knowledge and agricultural production realities. This transformation improves the efficiency of extension interventions, strengthens farmers' trust in proposed solutions, and increases rates of agricultural innovation adoption (Schuurman et al., 2016; Westerlund et al., 2018). Accordingly, living labs represent one of the most institutionally robust models for advancing Agricultural Knowledge and Innovation Systems by fostering actor integration, strengthening participatory learning, and supporting the transition toward more sustainable and resilient agricultural development pathways.

1.3. Roles of Agricultural Extension within the Living Labs Model

This axis constitutes the applied core of the transformation introduced by living labs within the agricultural extension system. Agricultural extension is no longer merely a channel for transferring technical knowledge or providing production recommendations; rather, it has become a central institutional actor in managing agricultural innovation, organizing community learning, building capacities, and supporting sustainability. This transformation reflects a profound redefinition of the mission of agricultural extension and its operational and strategic roles, enabling it to respond effectively to the complex environmental, economic,

and social challenges facing contemporary agriculture, which require integrated participatory solutions that go beyond the logic of limited linear interventions.

1.4. Functional Transformation of Agricultural Extension under Living Labs

Living labs reflect a structural shift in the philosophy and practice of agricultural extension, whereby extension moves from a traditional model focused on the transfer of technical knowledge to a multi-level participatory innovation model based on facilitation, knowledge intermediation, capacity building, and community innovation management. This transformation responds to the growing complexity of environmental, economic, and social challenges facing contemporary agricultural systems, for which linear technical recommendations are no longer sufficient, thus necessitating new extension roles characterized by flexibility and institutional integration (Potters et al., 2022).

1.5. Agricultural Extension as an Innovation Intermediary within the Innovation System

The role of the agricultural extension agent is redefined as an innovation intermediary who coordinates interaction among farmers, researchers, governmental institutions, the private sector, and civil society organizations, and aligns scientific knowledge with local production realities. This role extends beyond knowledge transfer to include organizing dialogue among diverse actors, facilitating trust-building, and transforming field-level problems into opportunities for innovation. Studies have confirmed that this intermediary role constitutes a structural prerequisite for the success of open innovation, as it helps narrow the gap between research and application, enhances farmers' trust in proposed solutions, and increases the adoption rates of new agricultural innovations (Schuurman et al., 2016; Westerlund et al., 2018).

1.6. Management of Participatory and Experiential Learning

Within living labs, agricultural extension assumes a central function in managing participatory and experiential learning by organizing interactive environments for the exchange of tacit and explicit knowledge, facilitating the joint experimentation of solutions, and evaluating them through iterative processes based on continuous feedback. This learning mode contributes to the development of participants' cognitive and behavioral skills, enhances their capacity to make more informed production decisions, and strengthens their ability to adapt to climatic and economic risks, thereby supporting the construction of more resilient and sustainable agricultural systems (Herth et al., 2024; Filho et al., 2023).

1.7. Empowerment of Farmers and Local Institutions

Through living labs, agricultural extension contributes to empowering farmers and local institutions by involving them in innovation-related decision-making, developing their organizational and technical skills, and strengthening their professional and social networks. This empowerment shifts farmers from the position of solution recipients to that of active partners in the production of innovation itself, which represents a fundamental pillar for building more inclusive and sustainable agricultural and food systems and a solid foundation for achieving balanced rural development (Trivellas et al., 2023; Potters et al., 2022).

1.8 Redefining the Strategic Mission of Agricultural Extension

Living labs reshape the functional structure of agricultural extension from a traditional model centered on knowledge transfer to a multi-level participatory innovation model focused on facilitation, knowledge intermediation, and capacity building. The literature confirms that this transformation is necessary in contemporary agricultural systems characterized by complex environmental, economic, and social challenges, where linear technical recommendations are no longer capable of providing effective responses (Potters et al., 2022). In this context, living labs do not merely represent a tool for improving the technical performance of agricultural extension; rather, they constitute an institutional framework that redefines its mission and strategic functions, shifting from the provision of limited-impact technical services to leading community innovation processes, building knowledge capital, enhancing the adaptive capacity of agricultural systems, and supporting the transition toward more sustainable and resilient development pathways (Filho et al., 2023; Herth et al., 2024).

2. DEVELOPMENTAL AND APPLIED IMPACTS OF LIVING LABS IN AGRICULTURE

Living labs represent a central developmental model in the contemporary transformations of agricultural and food systems, as their impact

extends beyond the development of technical solutions to encompass the restructuring of institutional frameworks, patterns of community interaction, and mechanisms of developmental decision-making. This model is regarded as one of the most capable frameworks for responding to the complex challenges facing modern agriculture, particularly those related to environmental sustainability, food security, climate change, and the limited resilience of rural communities (Filho et al., 2023; Herth et al., 2024).

2.1. Environmental Impact and Sustainability Building

At the environmental level, living labs contribute to transforming sustainability from a theoretical concept into an applied practice by testing agricultural solutions in real-life use environments and engaging farmers in the design and evaluation of sustainable practices. This approach enhances the capacity of agricultural systems to manage natural resources more efficiently, reduce negative environmental impacts, and adopt production practices that are more aligned with local ecosystems (Trivellas et al., 2023; Filho et al., 2023). Studies also indicate that this form of participatory innovation strengthens the ability of agricultural communities to adapt to climate risks, as living labs enable the gradual testing of adaptation and mitigation strategies. This reduces the uncertainty associated with adopting new environmental innovations and enhances trust in sustainable solutions (Herth et al., 2024).

2.2. Economic Impact and Enhancement of Productive Efficiency

Economically, living labs represent an important driver for improving resource-use efficiency, increasing agricultural productivity, and developing innovative business models based on cooperation and knowledge exchange. This is largely attributed to the active involvement of farmers in innovation processes, which leads to the development of solutions that are more closely aligned with production realities and more adoptable and sustainable over time compared to solutions designed in isolation from end users (Potters et al., 2022; Schuurman et al., 2016). In addition, living labs facilitate the development of local economic networks that connect producers to markets and enhance access to resources and services, thereby improving the competitiveness of small-scale farmers and reducing economic disparities within rural communities (Westerlund et al., 2018).

2.3. Social and Institutional Impact and Community Capital Building

From a social and institutional perspective, living labs contribute to building strong social capital by enhancing trust among actors, expanding cooperation networks, and supporting community participation in decision-making processes. This pattern of interaction empowers local communities to exert greater control over their development trajectories and to achieve higher levels of inclusion and equity in the distribution of development benefits (Trivellas et al., 2023; Filho et al., 2023). Living labs also support the institutional capacity development of agricultural extension by transforming it into a central actor in managing community innovation, coordinating participatory learning processes, and building cross-sectoral partnerships, thereby strengthening local governance and supporting the long-term sustainability of development interventions (Herth et al., 2024; Potters et al., 2022).

2.4. Living Labs as a Lever for Resilience and Long-Term Development

Living labs represent a strategic instrument for building resilience within agricultural systems by enabling communities to respond effectively to environmental, economic, and social shocks and to transform crises into opportunities for learning and innovation. This dimension constitutes one of the most significant developmental contributions of living labs, as agricultural development shifts from the logic of temporary interventions to a logic centered on building long-term endogenous capacities (Filho et al., 2023; Herth et al., 2024).

2.5. Differences between Farmer Field Schools and Living Labs

Farmer Field Schools and living labs are among the most prominent participatory approaches used in the development of agricultural extension. However, the difference between them is structural in terms of philosophy, function, and institutional role. Farmer Field Schools are primarily based on the philosophy of participatory learning and focus on empowering farmers to improve their existing agricultural practices through experimentation and collective learning in the field. Their main objective is to enhance farmers' productive performance and strengthen their capacity to make more informed technical decisions (Table 1).

In contrast, living labs are grounded in the philosophy of participatory innovation. Rather than

merely improving existing practices, they aim to generate new solutions and redesign the agricultural system itself. Their scope extends beyond the field level to encompass the entire agricultural system, including institutional relationships, decision-making mechanisms, and Agricultural Knowledge and Innovation Systems.

The scope of participation also differs between the two models. In Farmer Field Schools, participation is largely confined to an educational framework involving farmers and agricultural extension agents. Living labs, by contrast, rely on multi-actor participation that includes, in addition to farmers and extension agents, researchers, policymakers, the private sector, and civil society organizations, thereby creating a richer and more integrated innovation environment.

Differences are also evident in the nature of outputs. Farmer Field Schools focus on knowledge transfer and the improvement of practices, whereas living labs generate new applied innovations that are tested, evaluated, and scaled through a systematic innovation cycle encompassing diagnosis, design, experimentation, evaluation, and scaling. Moreover, the role of agricultural extension in Farmer Field Schools is often limited to educational facilitation, while in living labs it evolves into that of an institutional driver and innovation intermediary leading comprehensive change processes. Accordingly, Farmer Field Schools represent an effective educational tool within the agricultural extension system, whereas living labs constitute an advanced institutional framework for managing innovation and agricultural transformation, making them more suitable for addressing the complex challenges facing the contemporary agricultural sector.

Table 1: Differences between Farmer Field Schools and Living Labs.

Comparative Dimension	Farmer Field Schools	Living Labs
Core philosophy	Participatory education aimed at improving agricultural practices	Participatory innovation aimed at generating new solutions
Primary role	Building farmers' knowledge and skills	Producing applied, institutionalized innovation
Nature of participation	Educational participation between farmers and extension agents	Multi-actor participation (farmers, researchers, policymakers, private sector, etc.)
Scope of operation	Field and farm level	Entire agricultural system level
Type of outputs	Improvement of existing agricultural practices	Development of new solutions and innovations
Methodology	Learning by doing and experimentation	Innovation cycle: diagnosis → design → experimentation → evaluation → scaling
Institutional role of extension	Educational facilitator	Institutional driver and innovation intermediary
Sustainability	Short- to medium-term educational programs	Long-term institutional operational mechanism
Policy linkage	Often weak	Strong and direct
Approach to complexity	Limited	High (environmental, economic, social, and institutional)

3. METHODOLOGY

This paper adopts a conceptual–analytical approach as the most appropriate methodological framework for examining complex institutional phenomena related to living labs and the transformations of contemporary agricultural extension. This approach aims to develop an interpretive framework and an integrated operational model rather than to test field-based hypotheses, in line with the nature of the paper as a theoretical and analytical study.

The analysis is grounded in a comparative critical review of specialized literature on living labs, Agricultural Knowledge and Innovation Systems (AKIS), participatory innovation, sustainability, and resilience building. This review deconstructs the conceptual structures of the literature and identifies key research gaps, particularly the limited attention given to the institutional leadership role of agricultural extension within living lab systems. The development of conclusions relies on theoretical induction and on linking conceptual insights to the practical and operational needs of the agricultural extension sector, especially in developing contexts characterized by limited human and financial resources and weak institutional coordination. This analytical pathway enabled the development of an integrated operational model (PAI-LLM) that systematically illustrates how living labs can contribute to modernizing the roles of agricultural extension, enhancing its institutional and developmental effectiveness, and supporting the formulation of more responsive extension policies capable of addressing the complexities of current agricultural challenges.

3.1. Critical Review of Previous Literature

Contemporary literature (Table 2) indicates a growing interest in the use of living labs to support

agricultural innovation and the sustainable transformation of food systems. The study by Trivellas et al. (2023) is among the closest to the agricultural domain, as it presents an integrated conceptual framework for Agro Living Labs as an approach to enhancing sustainability, resilience, and social inclusion within food systems. However, despite its theoretical strength, this study does not provide a clear operational vision for how living labs can be managed in practice, nor does it specify the role that agricultural extension could play within this framework. The present paper seeks to address this gap by developing an operational model that places agricultural extension at the core of the living lab system. In the same context, the study by Potters et al. (2022) stands out as one of the most closely aligned with agricultural extension and Agricultural Knowledge and Innovation Systems (AKIS), as it demonstrates that living labs can serve as an effective tool for enhancing participatory learning and network building within these systems. Nevertheless, this study treats agricultural extension as one element within the innovation network, without assigning it the coordinating leadership role required for the effective operation of living labs. The present paper reconceptualizes this role by positioning agricultural extension as an institutional driver of participatory innovation.

The review by Filho et al. (2023) provides strong support for the linkage between living labs, sustainability transitions, and resilience building in agricultural and food systems. However, the predominantly optimistic normative tone of the analysis limits the depth of its engagement with the institutional and structural challenges associated with implementing this model in developing rural contexts. From this standpoint, the present paper integrates the institutional dimension of agricultural extension as a critical condition for translating theoretical frameworks into sustainable development practices. On the other hand, the study by Herth et al. (2025) contributes to a deeper understanding of the role of living labs in supporting sustainability transitions, while highlighting operational challenges related to governance, coordination, and multi-actor involvement. Yet, its focus on the university context constrains the direct transferability of its findings to the agricultural domain. The present paper addresses this limitation by recontextualizing these challenges within agricultural extension systems and rural production environments.

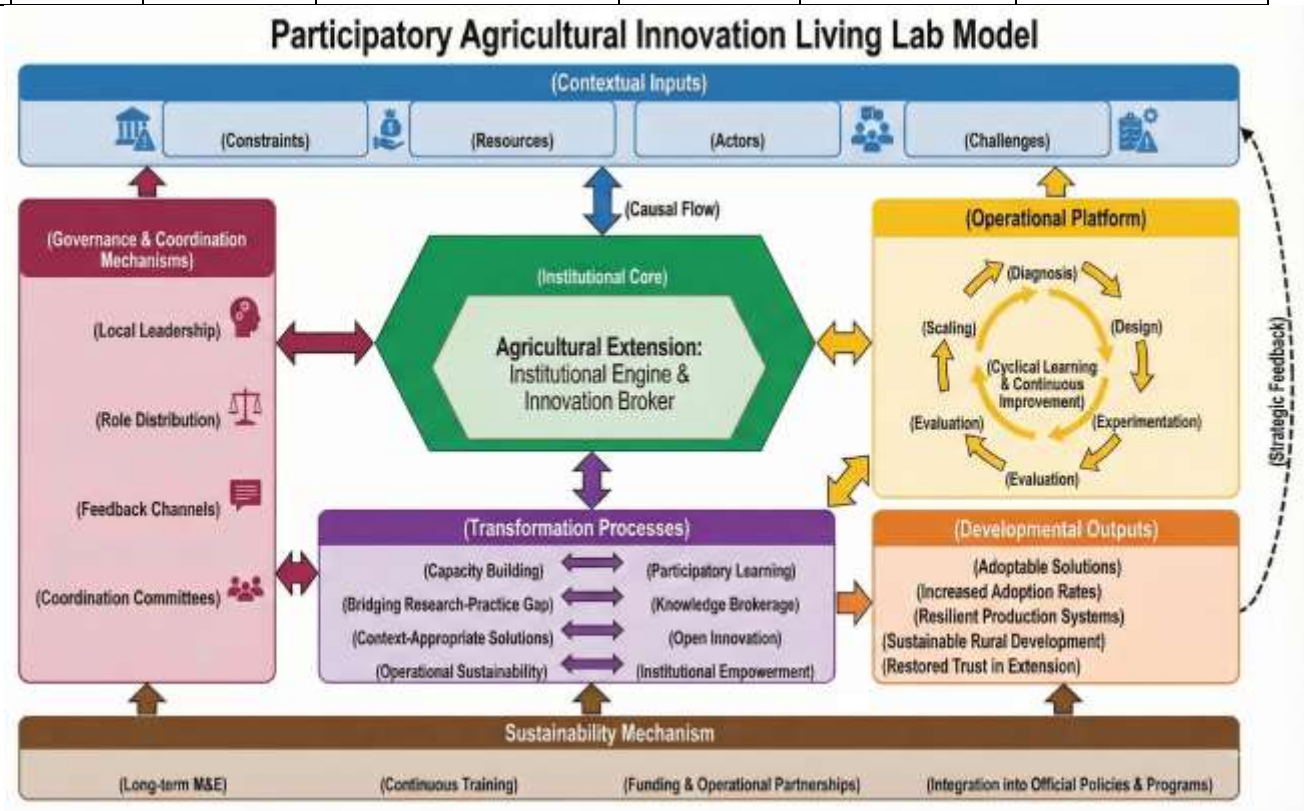
With regard to the theoretical foundations of living labs, the studies by Schuurman et al. (2016) and Westerlund et al. (2018) provide a fundamental contribution by clarifying the role of innovation intermediation and the importance of intermediaries in the success of open innovation within living labs. However, these studies do not clearly identify which actors can assume this role within agricultural systems. The present paper seeks to resolve this ambiguity by proposing agricultural extension as the most appropriate institutional innovation intermediary for this function.

Although the studies by Bridi et al. (2022), Archibald et al. (2021), Toso et al. (2023), and Ovaci (2020) are relatively distant from the direct agricultural context, they offer valuable insights into the operational challenges of living labs, participatory learning mechanisms, and the structure of multi-actor innovation networks. The present paper draws on these contributions by adapting them to the realities of agricultural extension and rural development, thereby contributing to a more mature and realistic conceptualization of activating living labs within the agricultural sector. This critical review concludes that, despite the richness of the literature, a clear gap remains in the systematic linkage between living labs and agricultural extension as a central institutional actor. This is the gap that the present paper seeks to address by reconstructing the role of agricultural extension within the living labs model in a manner that serves the goals of sustainability, resilience, and inclusive rural development.

Table 2: Critical Analysis of Previous Studies Most Relevant to the Agricultural Domain.

No.	Study	Focus Area	Main Contribution	Strengths	Research Gaps	Position of the Present Paper
1	Trivellas et al., 2023	Agro Living Labs and food systems	Conceptualization of agro living labs to support sustainability, resilience, and inclusion	Direct linkage to agriculture and food systems	Weak operational mechanisms and limited role of extension	The paper develops an operational model integrating extension within living labs
2	Potters et al., 2022	AKIS and agricultural extension	Demonstrates the role of living labs in strengthening agricultural knowledge and innovation systems	Strong relevance to extension and policy	Extension presented as a network element rather than a driver	The paper repositions extension as a coordinating leader
3	Filho et al.,	Living labs and	Links living labs to	Broad systematic	Optimistic normative	The paper adds the

	2023	sustainability transitions	sustainability and resilience	review	framing with limited institutional analysis	institutional dimension of extension
4	Herth et al., 2025	Living labs and transitions	Analysis of innovation potential and operational challenges	Identifies governance and coordination issues	University-oriented focus rather than production systems	The paper transfers the analysis to agriculture and extension
5	Schuurman et al., 2016	Open innovation and living labs	Highlights the role of the innovation intermediary	Robust theoretical framework	Does not specify who assumes the intermediary role in agriculture	The paper identifies extension as the innovation intermediary
6	Westerlund et al., 2018	Living lab research trends	Analysis of field development	Comprehensive and wide-ranging analysis	Weak linkage to agricultural development	The paper applies the findings to extension policy
7	Bridi et al., 2022	Living labs and local development	Clarifies operational and governance challenges	Rich applied analysis	Limited linkage to the agricultural sector	The paper adapts the findings to the agricultural extension context
8	Archibald et al., 2021	Participatory learning in living labs	Analysis of learning and interaction mechanisms	Strong methodology	Non-agricultural application	The paper generalizes the approach to extension and rural development
9	Toso et al., 2023	Participatory innovation networks	Highlights multi-actor collaboration structures	Advanced network analysis	Weak linkage to agricultural production	The paper aligns the results with AKIS
10	Ovaci, 2020	Living lab networks	Global mapping of living labs	Holistic view of institutional structures	Descriptive analysis without applied interpretation	The paper builds an institutional interpretation centered on extension



3.2. Explanation of the Participatory Agricultural Innovation through Living Labs Model

This section presents the proposed conceptual and operational model for participatory agricultural innovation through living labs as an integrated institutional framework for restructuring the agricultural extension system and enhancing the effectiveness of Agricultural Knowledge and Innovation Systems in addressing contemporary challenges. The model is based on integrating agricultural extension at the core of the innovation process, positioning it as the institutional driver and innovation intermediary that leads interaction among different actors and transforms knowledge

into applied solutions that are adoptable and sustainable. This section also clarifies the seven components of the model, the interrelationships among them, and the operational and governance mechanisms that ensure its institutional effectiveness and its capacity to achieve sustainable developmental impact in rural agricultural contexts, as outlined below.

1: Contextual Inputs

This component represents the starting point of the proposed model, as it defines the real-world framework upon which all subsequent processes within the agricultural living lab are built. These inputs are not viewed as static parameters, but rather as a dynamic system that continuously interacts with the innovation and learning processes led by agricultural extension.

First: Challenges

Contextual challenges include a set of compounded pressures facing the agricultural sector, foremost among them the impacts of climate change on agricultural production and stability, fluctuations in input and output prices and the resulting economic uncertainty, and increasing pressures on natural resources, particularly water and agricultural land. In addition, there exists a persistent adoption gap between available knowledge and farmers' actual practices. These challenges constitute the primary driver for the need for flexible participatory innovation models, such as living labs, that are capable of responding rapidly to complex changes in the agricultural environment.

Second: Actors

The institutional field of the model consists of a multi-actor network that includes farmers as the central focus of the innovation process, researchers as the source of scientific knowledge, agricultural extension agents as the innovation intermediary and operational leader of the model, governmental bodies responsible for policy and regulation, and the private sector as a partner in financing, technology provision, and marketing. This diversity of actors establishes a strong foundation for participatory innovation, in which different forms of expertise, knowledge, and interests are integrated within a single system.

Third: Resources

The model relies on maximizing the use of locally available resources rather than depending on high-cost external inputs. These resources include the accumulated local knowledge of farmers, the research expertise available in universities and research centers, and the existing extension infrastructure, which represents the primary institutional channel for field-level implementation of the model. This strategic utilization of resources constitutes one of the most important elements of the model's sustainability and its applicability in resource-constrained settings.

Fourth: Constraints

The model does not overlook the institutional and structural constraints governing the agricultural reality; rather, it explicitly incorporates them into its design. These constraints include limited funding available for extension and agricultural development activities, weak coordination among research, extension, and implementation agencies, and centralized decision-making that restricts the flexibility of local interventions. Integrating these constraints into the contextual inputs contributes to the development of a realistic and implementable model that takes actual capacity limits into account when formulating innovative solutions.

2: The Institutional Core of the Model – Agricultural Extension

Within the proposed model, agricultural extension represents the institutional core around which all operational processes of the living lab revolve. It is redefined as the institutional driver and innovation intermediary responsible for transforming contextual inputs into implementable and sustainable pathways of innovation and development. Its role is not limited to the provision of traditional technical services; rather, it expands to include leading the entire innovation system at both local and regional levels.

First: Institutional Coordination Leadership

Agricultural extension assumes responsibility for coordinating relationships among the various actors within the living lab system, including farmers, researchers, governmental bodies, the private sector, and civil society organizations. This coordination aims to align roles, consolidate efforts, and avoid duplication, thereby ensuring that resources are directed toward clear and shared development priorities and enhancing the efficiency of agricultural interventions.

Second: Management of the Participatory Innovation Cycle

Agricultural extension leads the participatory

innovation cycle across all its stages, beginning with the diagnosis of field-level problems, followed by the design, experimentation, and evaluation of solutions, and culminating in the scaling and dissemination of successful innovations. This role ensures that the innovation process remains closely linked to farmers' production realities and is adaptable to changing environmental, economic, and social conditions.

Third: Facilitation of Community Learning

Agricultural extension plays a central role in facilitating community learning by organizing interactive spaces for dialogue and experience exchange among farmers and other stakeholders, and by promoting the generation of applied knowledge based on experimentation, trial and error, and continuous feedback. This learning mode contributes to building the capacities of farmers and local institutions and enhances their ability to adapt to agricultural risks and challenges.

Fourth: Ensuring Continuity and Governance

Agricultural extension serves as the institutional guarantor of the continuity of the living lab's operation by establishing clear governance frameworks for participation and decision-making and by developing continuous monitoring and evaluation mechanisms. These functions ensure alignment between the model's objectives and broader agricultural and development policies and strengthen the long-term sustainability of outcomes.

3: Operational Platform – The Agricultural Living Lab

Within the proposed model, the agricultural living lab represents the central operational platform through which the institutional vision and leadership functions of agricultural extension are translated into tangible field practices. The living lab is not conceived as a physical site or a temporary project, but rather as a continuous operational mechanism managed cyclically through a sequence of integrated stages that ensure the generation of realistic agricultural solutions that are adoptable and sustainable.

First: Diagnostic Phase – Analysis of Field Problems

The innovation process begins with an accurate diagnosis of the problems faced by farmers in the field. Agricultural extension leads the collection of field data, analyzes the environmental, technical, and economic causes of these problems, and prioritizes them according to farmers' needs and their impact on production and agricultural stability. This phase constitutes the foundation upon which all subsequent decisions are built.

Second: Design Phase – Development of Participatory Solutions

At this stage, agricultural extension facilitates participatory working sessions that bring together farmers, researchers, and other relevant actors to generate a range of possible solutions for each identified problem, followed by the selection of the most realistic and locally feasible options based on available community resources. This interaction results in solutions that are flexible and context-adapted, while also strengthening farmers' sense of shared ownership over the proposed interventions.

Third: Experimentation Phase – Field Testing

The designed solutions are implemented in actual agricultural fields through field trials conducted under the supervision of agricultural extension and with the active participation of farmers and researchers. This practical testing allows for the assessment of solution feasibility under real production conditions and enables early identification of strengths and shortcomings prior to wider dissemination.

Fourth: Evaluation Phase – Impact Measurement and Learning

Agricultural extension leads the evaluation process by measuring the productive, economic, and environmental impacts of the implemented solutions, while also documenting farmers' experiences and feedback. These results are discussed in participatory learning sessions that facilitate the extraction of lessons learned and the introduction of necessary adjustments to the solutions, thereby improving the quality of future decision-making.

4: Governance and Coordination Mechanisms

This component constitutes the organizational framework that ensures the stability of the agricultural living lab's operation and prevents it from devolving into fragmented initiatives or uncoordinated activities. Governance and coordination mechanisms aim to regulate roles, organize relationships among actors, and enhance transparency and accountability, thereby supporting the model's effectiveness and institutional sustainability.

First: A Local Leadership Structure Led by

Extension

The model proposes the establishment of a local leadership structure for the agricultural living lab led by the agricultural extension institution, as the actor most closely connected to the agricultural field and the most capable of ensuring operational continuity. This structure is responsible for setting strategic directions, approving work plans, and overseeing the implementation of the stages of the innovation cycle, while taking into account the environmental, social, and economic characteristics of each locality.

Second: Clear Definition of Roles and Responsibilities

The model relies on a clear allocation of roles and responsibilities among all participating actors, including farmers, researchers, governmental bodies, the private sector, and civil society organizations. This clarity helps reduce institutional overlap and duplication of efforts, enhances coordination efficiency, and ensures that each actor assumes responsibility for achieving the objectives of the living lab.

Third: Continuous Feedback Channels

The model is built on the establishment of effective communication and feedback channels among all partners, whether through periodic meetings, digital platforms, or field visits. These channels enable the continuous exchange of information, timely identification of operational challenges, and rapid corrective decision-making, thereby enhancing the model's flexibility and capacity to adapt to changing conditions.

Fourth: Multi-Actor Coordination Committees

The model supports the formation of coordination committees comprising representatives of all relevant actors. These committees address both strategic and operational issues of the living lab and function as a shared platform for decision-making and institutional consensus-building. They contribute to enhancing participation and transparency, strengthening trust among partners, and ensuring that collective efforts remain aligned with broader development objectives.

5: Transformative Processes

This component represents the dynamic core of the proposed model, through which inputs and operational activities within the living lab are transformed into tangible developmental outputs via a set of interrelated transformative processes led by the agricultural extension institution.

First: Participatory Learning → Capacity Building

The model is grounded in participatory learning as a central mechanism for generating applied knowledge. Farmers, researchers, and agricultural extension agents exchange their experiences and practices within interactive environments based on dialogue, experimentation, and continuous feedback. This mode of learning builds technical, organizational, and behavioral capacities among all participants, enhancing their ability to make more informed and effective agricultural decisions.

Second: Knowledge Intermediation → Bridging the Research–Practice Gap

Agricultural extension assumes the role of a knowledge intermediary that links scientific knowledge with production realities. It translates research findings into practical, field-applicable solutions, while simultaneously conveying farmers' problems and experiential insights to researchers in order to inform research agendas. This intermediation contributes to narrowing the traditional gap between research and practice and to improving the overall efficiency of the agricultural innovation system.

Third: Open Innovation → Context-Appropriate Solutions

The model adopts an open innovation philosophy that enables the involvement of all actors in the generation, testing, and refinement of solutions, rather than relying on closed innovation pathways. This openness leads to the development of agricultural solutions that are flexible and adapted to local environmental, social, and economic conditions, thereby increasing their likelihood of success and long-term sustainability.

Fourth: Institutional Empowerment → Operational Sustainability

The model contributes to the empowerment of local institutions, foremost among them the agricultural extension system, by strengthening their organizational and coordination capacities and by building effective partnership networks with diverse stakeholders. This empowerment supports the operational sustainability of the living lab, allowing it to become an integral component of the agricultural system rather than a temporary initiative or short-lived project.

6: Developmental Outputs

This component represents the outcome of the systematic interaction among contextual inputs, the institutional structure, operational and governance mechanisms, and transformative processes within the proposed model. The final results materialize in a set of developmental outputs that reflect the tangible impact of activating living labs within agricultural extension.

First: Adoptable Agricultural Solutions

The model generates practical agricultural solutions that are developed and tested within the real context of agricultural fields, with farmers actively involved in all stages of the innovation process. This approach ensures that solutions are aligned with local environmental, economic, and social conditions, thereby enhancing their applicability and diffusion.

Second: Increased Adoption Rates

Owing to the participatory nature of the living lab, farmers move from being passive recipients to active partners in the production of solutions. This shift increases trust in the proposed innovations and leads to higher adoption rates compared to traditional extension models based on one-way transfer of recommendations.

Third: More Resilient Production Systems

The model contributes to building agricultural production systems that are more capable of adapting to environmental and economic shocks by strengthening the capacities of farmers and local institutions to manage risks, diversify solutions, and improve resource-use efficiency. These outcomes support the long-term sustainability of agricultural production.

Fourth: Sustainable Rural Development

The impact of the model extends beyond the field level to encompass broader developmental dimensions. It contributes to improving rural livelihoods, enhancing economic and social stability, and supporting the sustainable management of natural resources, in line with the objectives of comprehensive agricultural and rural development.

Fifth: Restoring Trust in Agricultural Extension

The model contributes to rebuilding trust between farmers and agricultural extension institutions by demonstrating the effectiveness of extension interventions and their direct impact on improving production and income, as well as by strengthening farmers' sense of shared ownership of the proposed solutions. This process restores the position of agricultural extension as a key partner in agricultural development.

7: Sustainability Mechanism

This component aims to ensure the continued effectiveness of the proposed model and the expansion of its impact beyond the initial pilot phases, so that the agricultural living lab does not remain a temporary initiative but becomes an integral part of the national agricultural extension and agricultural development system.

First: Integration of the Model into Official Extension Programs

The model emphasizes the need to integrate living lab activities into the official plans and programs of agricultural extension institutions. This integration ensures continuity of implementation, institutional support, alignment with national agricultural policies, and independence from short-term projects or temporary funding sources.

Second: Financing and Operational Partnerships

The model proposes the development of a multi-actor financing and operational partnership system involving governmental bodies, the private sector, research centers, and development organizations. Such partnerships enable the sharing of costs and risks and provide sustainable financial and technical resources to support the continued operation and scaling of the living lab.

Third: Continuous Training through Living Labs

The model relies on the living lab itself as a continuous field-based learning environment for developing the skills of agricultural extension agents, farmers, and other stakeholders through learning by doing, joint experimentation, and experience exchange. This approach reduces dependence on conventional training programs with limited impact.

Fourth: Long-Term Monitoring and Evaluation System

The model underscores the importance of establishing a long-term monitoring and evaluation system that measures the productive, economic, social, and environmental impacts of the model's implementation, tracks its evolution over time, and enables continuous improvement of operational and

governance mechanisms. This system strengthens the sustainability of outcomes and supports the achievement of the intended development objectives.

3.3. Significance of Implementing the Proposed Operational Model

The proposed operational model is grounded in a realistic understanding of the structural challenges facing agricultural extension in Egypt, including limited financial resources, a shortage of qualified personnel, weak institutional coordination between research, extension, and implementation, declining societal trust in the effectiveness of extension services, as well as centralized decision-making and limited organizational flexibility. Rather than treating these constraints as marginal obstacles, the model positions them as the primary point of departure in its design. The significance of implementing this model can be summarized as follows:

1. Repositioning Agricultural Extension despite Institutional Constraints

In the context of limited resources and weak traditional structures, the model proposes shifting agricultural extension from a "service delivery" logic to a low-cost participatory innovation management approach. Under this model, the extension agent becomes a coordinator of innovation processes within the local community, drawing on available community resources, local knowledge, and partnerships with universities and the private sector, rather than relying exclusively on government budgets.

2. Addressing the Institutional Coordination Gap

The model tackles weak linkages between research and extension by transforming the living lab into a continuous institutional coordination platform led by agricultural extension. Research experiments are directly embedded in farmers' fields, and research priorities are reformulated based on real production problems, thereby reducing the traditional gap between scientific knowledge and agricultural practice.

3. Restoring Societal Trust in Agricultural Extension

The model addresses declining farmers' trust in extension services by shifting them from the role of passive recipients to active partners in the design, testing, and evaluation of solutions within the living lab. This participatory transition not only enhances adoption but also rebuilds the relationship between extension agents and farmers on the basis of mutual trust and shared ownership of solutions.

4. Overcoming Centralized Decision-Making and Limited Organizational Flexibility

The model introduces a higher level of operational decentralization by granting local extension units a leadership role in managing living labs according to the environmental and social characteristics of each area, while maintaining a coordinated national governance framework. This arrangement enables local innovation without compromising institutional coherence.

5. Strengthening Human Capacities amid Limited Staffing

The model addresses shortages of qualified personnel by adopting a learning-by-doing approach within living labs, whereby the lab itself becomes a permanent field-based school for developing the skills of both extension agents and farmers. This approach reduces reliance on costly and low-impact conventional training programs.

3.4. Contextual Considerations for Implementing the Model in Egypt

The implementation of the proposed operational model for activating living labs within agricultural extension in the Egyptian context is grounded in a set of practical considerations imposed by the institutional, economic, and social characteristics of the agricultural sector in Egypt. The success of any innovative model depends not only on its theoretical coherence, but also on the extent to which it is aligned with existing institutional structures and its ability to address the practical constraints governing agricultural extension performance on the ground.

The first consideration relates to the centralized nature of the agricultural extension system in Egypt and the associated limitations on local-level decision-making flexibility. This requires that the model be designed to allow for a calibrated degree of operational decentralization at the governorate and agricultural district levels, enabling living lab activities to be adapted to the environmental, economic, and social characteristics of each area, without undermining the overarching national framework of extension policies.

The second consideration concerns the limited financial and human resources available to agricultural extension. The proposed model does not assume the availability of substantial additional resources; rather, it is based on maximizing the use of existing community resources and building functional partnerships with universities, research centers, the private sector, and civil society organizations. Such partnerships enable cost sharing and enhance the financial and operational

sustainability of living labs.

The third consideration addresses the historically weak trust among segments of farmers in the effectiveness of traditional extension services. The model responds to this challenge by shifting farmers from the position of passive recipients to that of active partners in diagnosis, experimentation, and evaluation within the living lab. This participatory transition rebuilds trust on the basis of engagement and shared ownership of agricultural solutions.

The fourth consideration relates to the institutional coordination gap between scientific research, extension, and implementation. The proposed model restructures this pathway by positioning the living lab as a continuous institutional coordination platform led by agricultural extension, where research outputs are directly integrated into farmers' fields and research priorities are reformulated based on the needs of actual practice.

The fifth consideration concerns the need to enhance the competencies of extension personnel in the context of limited conventional training programs. The model proposes adopting living labs as a continuous field-based learning environment that enables the development of extension agents' skills through practice, interaction, and participatory learning, thereby contributing to the formation of more flexible human capacities capable of responding to the rapid changes occurring in the agricultural sector. Accordingly, the application of the proposed model in Egypt is not based on replicating international experiences, but rather on a careful alignment between the requirements of participatory innovation and the realities of the Egyptian agricultural extension system. This alignment ensures the model's practical applicability, institutional sustainability, and developmental viability.

4. CONCLUSION

This paper concludes that living labs represent one of the most innovative and institutionally robust approaches for restructuring the agricultural extension system and enhancing the effectiveness of Agricultural Knowledge and Innovation Systems in addressing contemporary environmental, economic, and social challenges. The analysis clearly demonstrates that the shift from a traditional extension model based on linear knowledge transfer to a participatory innovation model grounded in experiential learning, knowledge intermediation, and multi-actor partnerships is no longer a developmental option but an institutional necessity for ensuring the sustainability and resilience of agricultural systems.

The paper contributes to bridging a clear gap in the literature by repositioning agricultural extension as the central institutional driver and innovation intermediary within the living labs model, rather than treating it merely as one component of a broader innovation network. Through this reconceptualization, the study develops an integrated operational model that systematically links contextual inputs, institutional structures, governance and operational mechanisms, transformative processes, developmental outputs, and sustainability mechanisms. This integration enables the translation of theoretical innovation frameworks into implementable, scalable, and enduring field practices.

In the Egyptian context, the analysis reveals that the institutional crisis facing agricultural extension, most notably the sharp decline in the number of extension agents alongside persistent financial, organizational, and coordination constraints, cannot be effectively addressed through conventional solutions based on expanding personnel numbers or increasing public expenditure alone. Instead, this crisis necessitates a structural shift in operational logic. The Participatory Agricultural Innovation through Living Labs Model (PAI-LLM) emerges as a realistic and actionable strategic response by redefining the extension agent's role as an institutional driver and innovation intermediary and by transforming the living lab into a low-cost, high-impact community-based operational platform.

The findings demonstrate that, when activated through agricultural extension, living labs are capable of converting existing constraints such as limited resources, centralized decision-making, weak research–extension linkages, and declining societal trust into starting points for rebuilding the agricultural innovation system on more flexible, participatory, and sustainable foundations. Accordingly, living labs should not be viewed merely as a technical tool for improving extension performance but as a comprehensive institutional framework for redefining the role of agricultural extension as a leader of community-based innovation processes, a builder of knowledge capital, and a driver of sustainable rural development.

Finally, this study opens promising avenues for future research to examine the long-term impacts of living labs on food security, the resilience of agricultural systems, and quality of life in rural communities. Such research would further consolidate the position of the living labs model as a

strategic pillar of agricultural policy and innovation in developing countries.

5. RECOMMENDATIONS

In light of the findings of this paper, and taking into account the current institutional reality of agricultural extension in Egypt—particularly the sharp decline in the number of agricultural extension agents in the Arab Republic of Egypt, along with associated resource constraints, weak institutional coordination, and centralized decision-making—the paper proposes the following practical and implementable recommendations:

1. Shift from a manpower-intensive agricultural extension model to one based on participatory innovation management, redefining the extension agent's role as a coordinator of local innovation networks.
2. Adopt the living labs model to maximize extension agents' efficiency by positioning them as leaders of community innovation platforms without increasing staff numbers.
3. Restructure extension training programs to emphasize innovation intermediation, partnership management, participatory learning, and community change leadership.
4. Establish a flexible, decentralized governance framework for living labs that grants greater autonomy to local extension units in planning and implementation.
5. Expand multi-actor partnerships with universities, research centers, the private sector, and development organizations to ensure the sustainability of living labs.
6. Invest in low-cost digital solutions to extend geographical coverage, enhance communication with farmers, and improve knowledge documentation and transfer.
7. Develop simplified monitoring and evaluation systems focused on measuring the real developmental impact of living lab activities.

Conflict of Interest: The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

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