ISBN: 978-628-96613-1-6. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2025.1.1.1492

Technological Innovation Management Model for Urban Living Labs in Smart Cities: Strategies for Urban Problem-Solving

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Abstract*–. Urban Living Labs (ULLs) are pivotal frameworks for fostering socio-technical innovation in smart cities, addressing urban challenges through collaborative and adaptive solutions. This study introduces a socio-technical innovation management model that integrates community engagement, governance structures, and technological tools within ULL environments. By leveraging participatory processes and iterative testing, the model enhances the contextual relevance and scalability of smart city innovations. Focusing on the Fenicia Urban Living Lab in Bogotá, Colombia, the study explores the application of a digital twin platform to tackle urban challenges in waste, energy, and information management. To enhance stakeholder alignment, the model employs structured co-creation methodologies, multi-stakeholder governance frameworks, and data-driven decision-making, fostering collaboration among academia, industry, government, and local communities. Comparisons with global ULL practices underline the model's adaptability across diverse urban settings. While demonstrating its potential, the study identifies challenges such as digital infrastructure limitations in developing regions. The findings contribute to the broader discourse on sustainable urban development, proposing actionable strategies for inclusive and resilient cities. This research establishes a foundation for scaling ULL methodologies and evaluating their long-term socio-environmental impacts.

***Keywords*—Urban Living Labs (ULLs), Smart Cities, Socio-Technical Innovation, Digital Twin Platforms, Sustainable Urban Development.**

I. Introduction

Urban Living Labs (ULLs) have emerged as a pivotal framework for fostering innovation and experimentation in smart cities, offering collaborative environments where diverse stakeholders can co-create, test, and implement solutions to urban challenges. These laboratories play a critical role in addressing complex and multidimensional urban problems, such as sustainability, mobility, and equitable resource distribution, by integrating technological and social innovations. However, despite their potential, the practical implementation of technological innovation management models continues to face significant barriers, which limit their scalability and impact.

Recent studies have proposed diverse approaches for managing technological innovation within experimental urban environments. Integrated platforms are recognized for enabling open data exchange and fostering collaboration among multiple stakeholders to generate public value [1]. Socio-technical frameworks underscore the need to align technological innovation with urban objectives through cooperative dynamics [2]. In addition, cost-efficient strategies especially in developing regions demonstrate the practicality of leveraging simple technologies to improve urban conditions while minimizing resource use [3]. However, translating these models into sustained, actionable urban interventions remains a key challenge.

Notable gaps include institutional fragmentation and inertia, which impede the integration of these platforms into existing governance structures. Many initiatives prioritize short-term technological visibility over systemic and collaborative transformation. The lack of institutional mechanisms to sustain stakeholder engagement beyond initial enthusiasm or funding further limits their long-term viability. Moreover, technologies are often deployed without adequate adaptation to local socioeconomic and cultural contexts, reducing their effectiveness and acceptance. While community engagement is widely emphasized, the absence of scalable educational programs continues to restrict meaningful citizen participation in co-creation and develop of innovations.

To build upon these findings, this research proposes a new lens for examining the integration of socio-technical innovation strategies and technological innovation management models. It seeks to address how these elements can work together to overcome the identified gaps, ensuring that urban solutions are not only technologically advanced but also contextually relevant, collaborative, and inclusive. By focusing on these synergies, the research aims to enhance the effectiveness of ULLs in resolving urban challenges while promoting sustainable and inclusive development.

This leads to the central research question of this study: *How can socio-technical innovation strategies and technological innovation management models be integrated*

into Urban Living Labs (ULLs) to address urban challenges in smart cities in a sustainable and inclusive manner?

This paper addresses these gaps by proposing an integrated model for managing technological innovation in Urban Living Labs. Drawing on prior research and empirical data, the model combines socio-technical strategies [4], institutional frameworks, and scalable community engagement to enhance the capacity of ULLs to tackle urban challenges. By focusing on the practical limitations of existing frameworks, the study offers a pathway to align innovation management with sustainability, inclusion, and local relevance bridging the divide between theory and practice in smart city development.

Grounded in five socio-technical strategies: enhancing civic engagement, providing facilities for testing and co-creation, focusing on governance, linking technologies with urban dynamics, and integrating smart solutions this study uses the Fenicia Urban Living Lab at Bogota – Colombia as its application context. A digital twin platform is being developed to monitor neighbourhood issues such as waste management and renewable energy for an urban garden. This platform supports adaptive decision-making, strengthens community participation, and ensures that technological interventions respond to local needs.

In the current stage of implementation, the digital twin in the Fenicia ULL operates as a lightweight, community-oriented platform focused on territorial visualization, waste detection, and participatory mapping. The 3D spatial model of the neighbourhood was generated through drone based photogrammetry and integrated into a GIS environment using SuperMap. While this implementation supports data informed discussions and localized intervention planning, it still faces key limitations: (1) lack of real time data synchronization, (2) absence of institutional integration into city platforms, and (3) limited sensor deployment due to budgetary constraints. Despite these challenges, the digital twin functions as a critical tool for territorial learning, enabling iterative experimentation and citizen engagement.

This study highlights the need to align socio-technical innovations with the real needs of communities in developing urban contexts such as Bogotá, Colombia. By promoting local engagement and applying tools like digital twins, the research seeks to develop context-sensitive solutions that strengthen the waste–energy–information nexus. These innovations aim to generate local value through active community participation in their design, implementation, and maintenance, fostering ownership and long-term sustainability.

The proposed model integrates external drivers of urban transformation with the active involvement of stakeholders who co-create, test, and learn from innovations. It is designed to enhance quality of life, sustainability, and productivity by using ICT as a catalyst. By linking social, economic, and environmental dimensions through dynamic experimentation, the model supports scalable, impactful solutions rooted in local realities.

This research is informed by three critical gaps identified in the literature. First, there is limited analysis of sustainability strategies for urban transformation in developing countries. Second, while most socio-environmental studies emphasize the Water–Energy–Food nexus, there is a need to explore the underexamined Waste–Energy–Information nexus. Third, Urban Living Labs remain largely restricted to academic settings, underscoring the need to better integrate stakeholders in real urban contexts within developing regions. This study offers three key contributions to address these gaps:

- *Advancement in Contextualized Technological Innovation Management Models:* The research presents a comprehensive model that integrates socio-technical strategies while addressing the unique realities of communities in developing countries, such as those in Latin America. This adds to the scientific literature by offering a framework tailored to urban dynamics in these regions, filling a critical gap in the field.
- *Expansion of the Waste–Energy–Information Nexus in the Socio-Environmental Agenda*: By shifting focus from the traditional Water–Energy–Food nexus to the Waste–Energy–Information nexus, this study establishes a new research avenue that addresses pressing urban resource management challenges. This contribution provides actionable insights for sustainable urban solutions.
- *Enhanced Articulation of Stakeholders in Urban Living Labs in Developing Countries:* The research addresses the gap in living lab practices by proposing methods to integrate stakeholders in urban contexts beyond university campuses. This framework fosters collaboration among academia, communities, governments, and private sectors, facilitating transformative innovations with measurable social, economic, and environmental impacts.

This research leverages Urban Living Labs (ULLs) as platforms to develop and test socio-technical innovations with the potential to scale city-wide. The Fenicia ULL functions as an experimental space where diverse stakeholders co-create and refine smart city solutions, ensuring they are technically viable and contextually relevant before broader implementation. This approach promotes inclusive, sustainable urban transformation through dynamic, real-life experimentation.

Key contributions of the study include:

- A tailored ULL framework for addressing urban challenges in Fenicia and beyond.
- Integration of socio-technical strategies with tools like digital twins to support real-time, adaptive responses.
- A community-centered methodology that fosters participation, knowledge exchange, and local ownership.
- A scalable model designed to expand innovation impacts from the ULL to the wider city.
- A novel focus on the Waste–Energy–Information nexus for urban resource management.
- A governance model for pre-market testing of smart city solutions through stakeholder collaboration.

- Evidence of how ULLs can generate transformative innovations that respond to social, economic, and environmental needs in developing cities.

This paper is organized as follows: the first section introduces the research, defines the problem, and outlines the potential contributions. The second section reviews the relevant literature and describes the methods employed. Section three present the results, focusing on the development of the technological innovation management model, along with analysis and discussion. The final section concludes with a summary of all research activities conducted.

II. Literature Review and Background

ULLs serve as platforms for participatory experimentation and citizen empowerment, enabling co-creation processes that tackle complex urban challenges [5]. Several methodological approaches have guided ULL implementation. The Urban Lab Methodology (ULM) promotes adaptive co-design through open innovation and systems thinking [6]. The Full-Cycle Living Lab Model and FormIT offer structured and iterative design frameworks centered on user involvement and feedback [7][8].

More recently, digital platform ecosystems have supported virtual experimentation and wider engagement, though they may face limitations in simulating physical urban complexity [9]. Socio-technical frameworks add analytical depth by examining technological, institutional, and symbolic dimensions of innovation adoption [10]. The AMS Living Lab Way of Work complements these perspectives through a stepwise process from co-creation to replication, with emphasis on sustainability and iteration [11].

A comparative synthesis is provided in Table I. While these models offer valuable guidance, most lack contextual adaptability to socio-political realities in developing cities—an issue this paper addresses through a tailored innovation management model grounded in the Fenicia ULL.

TABLE I
Summary of Key Features, Strengths and Challenges of ULL Methodologies

ULL Methodology	Key Features	Strengths	Challenges
Full-Cycle Living Lab Model	- Based on the Double Diamond Design Framework - Emphasizes iterative processes (Discover, Define, Develop, Deliver) - Strong citizen participation - Structured public-private collaboration	- Systematic and adaptable - Encourages stakeholder involvement at all phases - Framework supports real-world testing and iterative improvements	- Complexity in managing diverse stakeholders - Requires significant coordination and resources
FormIT Methodology	- Spiral model: Design concepts, prototypes, and final systems - User-centered approach - Iterative validation in real-life contexts	- Continuous feedback loops - Emphasizes early-stage user engagement - Integrates narratives and user stories to define needs	- Time-consuming iterative processes - Risk of evolving user needs misaligning with project goals
Urban Lab Methodology (ULM)	- Combines Open Innovation Framework with Soft Systems Methodology - Encourages co-creation and dynamic stakeholder interactions	- Strong emphasis on managing external knowledge - Incorporates flexibility and adaptability - Applicable to complex urban challenges	- Requires advanced facilitation skills - Complexity in integrating heterogeneous stakeholder inputs
Helsinki Living Labs	- Phased approach: Grounding, Interactive Co-design, Appropriation & Implementation	- Supports scalable solutions - Emphasizes prototyping and user feedback - Strong focus on real-life testing	- Limited adaptability outside well-resourced urban contexts - Initial setup requires substantial investment
Digital Platform Ecosystems	- Digital environments simulate real-life scenarios - Encourages problem-solution matching - Focus on sustainability and entrepreneurship	- Effective for global-scale collaboration - Scalable for digital testing - Supports innovative business model development	- Limited engagement in physical urban spaces - Digital divide may exclude underrepresented populations
Socio-technical Framework	- Four perspectives: Technological, Instrumental, Collaborative, Symbolic - Analyses the integration of social and technological elements in innovation	- Comprehensive and multidimensional - Links technology adoption with collaborative governance - Addresses long-term project legitimacy	- Requires robust data collection and analysis - Symbolic value may conflict with instrumental goals
AMS Living Lab Way of Work	- Step-by-step guide: Initiation, Co-Creation, Implementation, Refinement, Replication	- Clear process alignment with urban needs - Strong focus on sustainability - Iterative and scalable	- May require additional steps to address context-specific challenges - Risk of overemphasis on procedural adherence

III. Methodology for Developing the Model

The methodology employed for developing the model was based on literature review, case studies analysis and expert interviews. The case study analysis focuses on examining exemplary ULLs to identify best practices and strategies that support the development of scalable and inclusive innovation models for smart cities. This approach aims to extract insights from diverse contexts, highlighting how these experimental environments address urban challenges through socio-technical innovations and collaborative governance.

A. Literature Review Analysis

The literature reviewed in Table 1 reveals key principles for constructing a technological innovation management model for urban challenges. Most approaches emphasize iterative development cycles that allow solutions to evolve through continuous feedback, aligning with socio-technical strategies within ULLs [4]. These iterations help address the dynamic nature of urban environments. Equally important is the inclusion of diverse stakeholders—citizens, governments, and businesses—in the co-creation process, reinforcing participatory governance frameworks [12].

A critical challenge emerges in balancing digital and real-life ULLs: while digital platforms offer scalability, they often lack sensitivity to local contexts [1]. This calls for hybrid models that combine digital reach with the contextual depth of physical ULLs.

Alignment with the Sustainable Development Goals (SDGs) is also growing [13], but standard models often fall short in capturing local specificity. Tailoring methodologies to local needs is essential for practical and lasting impact.

To overcome these gaps, capacity building is vital. Training and resources enhance stakeholder collaboration and long-term sustainability [4,13].

In sum, an effective model must integrate digital and physical ULLs, adopt iterative cycles, engage stakeholders actively, customize approaches to context, align with sustainability frameworks, and invest in capacity development ensuring inclusive and adaptive urban innovation.

B. Case Study Analysis

To capture the diversity of ULLs, this study analyzed cases from varied socio-economic and technological contexts. Eindhoven's Stratumseind integrates noise detection and data analytics to improve urban safety [10], while HIDS in Campinas, Brazil, exemplifies structured collaboration between academia, government, and industry toward sustainable development goals [13]. In Amsterdam, Buiksloterham uses open platforms for circular economy and adaptive regeneration [1], and Bandung's DDG Living Lab combines low-cost technologies with community engagement to address mobility and environmental issues [3].

A socio-technical framework guided the analysis across four dimensions: technological value (e.g., IoT, AI, big data) [4]; collaborative potential (quadruple helix partnerships) [12]; symbolic relevance (innovation narratives) [14]; and scalability/inclusivity (contextual adaptability) [1].

Findings reveal the importance of iterative experimentation (Eindhoven) [2], governance alignment (Campinas) [13], community-led regeneration (Amsterdam) [1], and participatory education (Bandung) [3]. In contrast, Fenicia ULL operates in a fragmented governance landscape with limited trust and institutional continuity. Unlike the formalized structures in the other cases, Fenicia relies on university-led facilitation and hybrid engagement strategies—ranging from structured workshops to informal outreach. Its digital twin remains in early stages, with minimal integration into local decision-making.

In contrast to the international cases, where participatory mechanisms are often embedded in stable governance ecosystems or enabled by institutional support (e.g., municipal platforms in Eindhoven or open co-design cultures in Amsterdam), the Fenicia ULL faces a context of institutional fragmentation, limited civic trust, and uneven policy continuity. Unlike Buiksloterham's bottom-up innovation culture or Campinas' formalized multi-stakeholder governance board, Fenicia depends on university led facilitation and hybrid modes of engagement, combining structured methods like workshops and Community Action Boards (CABs) with informal outreach strategies. Moreover, while digital platforms in the other cases serve as mature coordination or feedback systems, the digital twin in Fenicia is still in early stages, with limited integration into municipal decision making. This comparison highlights the adaptive but constrained nature of innovation in Fenicia, where experimentation occurs under conditions of governance volatility and resource scarcity. These constraints necessitate context specific mechanisms that blend institutional mediation with localized trust building to sustain participatory innovation.

C. Expert Interviews

Between February and November 2024, 15 semi-structured interviews were conducted with academic researchers, Bogotá district officials, and community members from the Fenicia ULL. The discussions focused on five core areas: civic engagement, co-creation infrastructure, governance, technological integration, and smart solutions. The diversity of participants enriched the analysis by incorporating multiple perspectives.

These interviews helped identify targeted strategies to strengthen each dimension of the ULL. The resulting proposals aim to align ULL activities with broader urban priorities, foster stakeholder collaboration, and ensure meaningful and context-sensitive use of technological innovations.

The semi-structured interviews included the following questions for five strategies:

Strategy 1: Foster Civic Engagement.

Question: *¿How can existing platforms and activities be improved to ensure that participation in the Urban Living Lab is not only more frequent but also more meaningful and satisfying?*

Strategy 2: Facilitate Testing and Co-Creation Facilities.

Question: *In your experience, ¿What elements do you consider essential for improving the testing and co-creation facilities in the Urban Living Lab, and how could these changes affect your ability to contribute?*

Strategy 3: Focus on Governance.

Question: *Considering the current governance structure of the Urban Living Lab, what aspects do you think could be modified to improve coordination and collaboration among the various stakeholders involved?*

Strategy 4: Linking Technologies with Urban Dynamics.

Question: *¿How do you evaluate the integration of new technologies in the urban life of the neighborhood, and what suggestions do you have to better align these technologies with the real needs and dynamics of the neighborhood?*

Strategy 5: Integrating Smart Solutions.

Question: *¿What barriers have you identified that impede the effective integration of smart solutions in the neighborhood, and what proposals do you have to overcome these barriers?*

Thematic analysis was used to examine interview data, combining inductive and deductive coding. Initial codes were based on the five strategies of the conceptual model and refined through open coding of transcripts. Patterns and stakeholder-specific concerns were identified across civic engagement, testing infrastructure, governance, technology integration, and solution adoption (see Table II). To ensure analytical robustness, we applied source triangulation, comparing perspectives from three actor groups: academic researchers, public officials, and community members. While formal software assisted coding (e.g., NVivo) was not employed, a structured matrix was used to organize responses thematically and support the interpretation of stakeholder-aligned strategies.

TABLE II
TRIANGULATION OF STAKEHOLDER PERSPECTIVES ACROSS INNOVATION STRATEGIES

Innovation Strategy	Academia	Local Government	Community
1. Civic engagement	Methodological design of workshops and participatory frameworks	Interest in structured participation via CABs	Appreciation of direct interaction with territory and activities
2. Testing and co-creation facilities	Need for prototyping spaces and technical resources	Lack of coordination across departments and permits	Expectations around equipment and training
3. Governance	Proposal of hybrid and adaptive governance models	Concerns about institutional sustainability	Low trust in authorities; interest in transparency
4. Linking technologies with urban dynamics	Use of data and AI for decision-making	Challenges integrating new technologies into existing systems	Doubts about the practical usefulness of the digital twin
5. Integrating smart solutions	Emphasis on scalability and replicability	Focus on technical and regulatory feasibility	Interest in everyday relevance, usability, and social appropriation

IV. ULL TECHNOLOGICAL INNOVATION MANAGEMENT MODEL

ULLs require a robust strategic foundation to ensure that their initiatives are effective, inclusive, and aligned with broader societal and urban objectives.

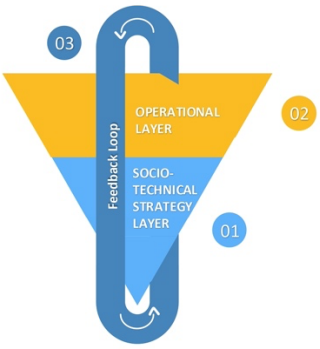

Fig. 1 Technological Innovation Management Model.

The innovation management model proposed in Figure 1 is structured in two interrelated layers: strategic and operational. The *strategic layer* defines the guiding vision, aligning ULL activities with sustainability goals, stakeholder participation frameworks, and systemic impact criteria. It includes the definition of KPIs, governance mechanisms, and coordination structures. *The operational layer*, by contrast, addresses how these strategies are implemented in practice through specific roles (e.g., coordinators, providers, users), co-creation activities, and data-driven tools such as the digital twin. While the strategic layer ensures coherence and long-term alignment, the operational layer enables iterative testing and community feedback integration. Figure 1 illustrates the interaction between both layers through feedback loops that allow constant adaptation and learning.

The strategic layer provides the foundation for decision-making and priority setting in the innovation management model. Based on Velasquez et al. [4], it integrates socio-technical strategies to align ULL initiatives with global goals like the SDGs and local urban agendas. This alignment ensures that innovation efforts contribute to sustainable, inclusive urban development.

Key strategies include: enhancing civic engagement through participatory frameworks; providing physical and virtual spaces for co-creation; and establishing adaptive governance to balance diverse stakeholder interests. The model also promotes linking technologies with urban dynamics to ensure contextual relevance and supports the integration of smart, scalable solutions to address urban challenges such as mobility and waste.

Through defined KPIs, this layer measures socio-technical, environmental, and economic outcomes, enabling transparent evaluation. Overall, the strategic layer connects innovation with real-world impact, fostering collaboration, adaptability, and continuous improvement.

SOCIO-TECHNICAL STRATEGY LAYER

A. Civic engagement in Fenicia ULL

For the Fenicia ULL, enhancing civic engagement is a multi-faceted strategy essential for the collaborative

development of smart city initiatives [15,16]. By actively involving citizens through various participative methods, the lab can leverage community insights and foster a sense of ownership over local projects. Here is how this strategy can be detailed:

1) Workshops and Community Action Board (CAB) Meetings: Organize regular community workshops and CAB meetings as forums for open dialogue between citizens and project leaders. These gatherings provide a space for residents to voice their concerns, share ideas, and contribute to the decision-making process. They can also serve to update the community on the progress of ongoing projects, fostering transparency and trust.

2) Digital Co-Design Platforms: Create and maintain digital platforms that facilitate virtual co-design sessions. These platforms can support diverse participation by overcoming geographical and temporal barriers, allowing wider demographic engagement, including those who may be unable to attend in-person events. Digital tools can range from simple survey forms to more complex collaborative design software, enabling real-time feedback and iterative design processes.

3) Effective Goal Setting and Policy Alignment: The necessity of establishing clear and prioritized goals to motivate participants is emphasized, ensuring that the objectives are specific and aligned with broader urban aspirations. Aligning activities with the city's vision and public policies ensures that the ULL's initiatives contribute meaningfully to overarching urban development goals. Emphasizing knowledge management and continuous learning, the lab spaces should be transformed into environments conducive to experimentation and iterative improvement. This approach fosters an atmosphere where participants are encouraged to engage frequently and contribute meaningfully to the ULL's mission.

Each of these approaches, while distinct in their application, shares the common goal of bolstering civic involvement. Collectively, they ensure that the Fenicia ULL not only garners a wide range of perspectives but also reinforces the community's role in shaping the future of the city.

B. Facilities for testing in Fenicia ULL

The Fenicia ULL neighborhood behaves as a testing space for socio-technical solutions. It is essential to foster a holistic approach to innovation that extends beyond mere technological development and accounts for the social fabric that underpins the city [17,18]. This would involve integrating diverse technologies and systems, ensuring a comprehensive testing ground that could pave the way for holistic urban solutions.

For Fenicia ULL, this suggests a direction towards testing labs that not only advance energy and environmental sustainability but also consider the socio-economic dynamics that shape urban living.

By aligning testing facilities with public policies and urban development plans, the Fenicia ULL ensures that innovations are seamlessly integrated into the broader urban landscape, avoiding counterproductive efforts and enhancing the effectiveness of urban development strategies. Collaborative and efficiently designed spaces will enable participants to work together more effectively, fostering a supportive environment for rapid application of innovative solutions. Furthermore, providing the necessary resources and training is crucial for empowering the community, enhancing their ability to utilize the facilities effectively, and fostering a culture of continuous learning and innovation. These combined efforts will ensure that the Fenicia ULL becomes a dynamic hub for testing and developing smart city technologies, contributing significantly to the city's overall innovation ecosystem.

To conclude, the Fenicia ULL can draw on the insights from Soutullo [18] to create an environment conducive to innovation. By providing facilities that mimic real life urban settings and challenges, Fenicia can become a breeding ground for innovations that are not only technologically advanced but also sustainable, socially integrated, and reflective of the complex dynamics of city life.

C. Governance strategy for Fenicia ULL

The governance strategy for Fenicia Urban Living Lab (ULL) would involve establishing a robust framework that orchestrates collaboration and innovation processes, balancing the interplay between different stakeholders (government, academia, private sector and neighborhood community), and aligning top-down and bottom-up approaches to innovation [19,20]. This entails several critical actions:

1) Institutional Framework and Leadership: A clear institutional structure should be in place, designating roles and responsibilities within the ULL. This includes setting up a governance board or review committee with representation from local authorities, private sector partners, academia, and neighborhood community.

2) Stakeholder Engagement: Actively engaging a diverse set of stakeholders ensures that the governance process is inclusive and grounded in the actual needs and capabilities of the local context. Strategies for engagement might include regular workshops, community action board (CAB) meetings, and the use of digital platforms for broader community involvement.

3) Policy Alignment and Strategic Focus: The governance model must be tightly aligned with broader city strategies and policies, particularly those related to technological innovation, economic development, sustainability, and social inclusion. It should focus on the strategic direction and long-term sustainability of the ULL.

4) Resource Allocation: Effective governance requires the strategic allocation of resources, both financial and human. This means securing funding, possibly through a mix of public investment, private sector partnerships, and grants, and assigning skilled personnel to manage the ULL's activities.

5) Regulatory Environment: Establish a supportive regulatory environment that allows for experimentation while ensuring compliance with legal and ethical standards. This could involve creating sandbox environments where new

technologies and approaches can be tested with fewer regulatory constraints.

6) Performance Monitoring: Implementing performance monitoring systems to track the progress of the ULL, evaluate the impact of innovations, and adjust governance practices as necessary. This includes setting up indicators for success and regular reporting mechanisms.

7) Communication and Transparency: Maintaining open lines of communication and ensuring transparency in decision-making processes to build trust among stakeholders and encourage their active participation.

8) Training and Inclusion: Providing training and development opportunities for stakeholders to enhance their understanding of smart city technologies and approaches, fostering a culture of innovation.

By implementing a clear and structured governance model, the Fenicia ULL can systematically address priority issues, ensuring that resources are allocated effectively and transparently. The establishment of a review committee aligns initiatives with the city's strategic goals, maintaining a focused and coordinated approach to urban development. Furthermore, emphasizing training and inclusion of citizens in the governance process not only enhances their ability to participate but also builds a collaborative community invested in the success of the ULL. These governance strategies collectively ensure that the ULL operates efficiently, inclusively, and in alignment with broader urban aspirations.

By focusing on these elements, Fenicia ULL can ensure its governance strategy is robust, dynamic, and capable of adapting to the evolving needs of a smart city

D. Linking Technologies with Urban Dynamics for Fenicia ULL.

Effective integration of smart solutions in the Fenicia ULL involves overcoming barriers and fostering collaboration:

1) Innovation Methodologies: Apply rigorous methodologies and innovation techniques, such as user-centered design and prototype validation, to enhance the efficiency and effectiveness of smart solutions.

2) Lack of Coordination: Identify and address coordination issues between municipal departments and other stakeholders. Improved communication and collaboration are essential for cohesive implementation of smart solutions.

3) Public-Private-Academic Collaboration: Strengthen collaboration between the public sector, private sector, and academia to tackle long-term challenges. Align efforts towards common objectives to drive sustainable and impactful urban development.

Applying rigorous methodologies such as user-centered design and prototype validation can significantly improve the efficiency and effectiveness of smart solutions. Additionally, an effective integration of smart solutions in the Fenicia ULL necessitates addressing coordination issues between municipal departments and stakeholders to ensure cohesive implementation. This requires enhanced communication and collaboration, which are crucial for overcoming barriers and fostering a unified approach. Furthermore, strengthening collaboration among the public sector, private sector, and academia is vital for tackling long-term challenges and aligning efforts towards common objectives [21,22]. Such collaboration will drive sustainable and impactful urban development, ensuring that smart solutions are effectively integrated into the Fenicia ULL, thereby enhancing urban living and fostering continuous innovation.

E. Integrating Smart Solutions for Fenicia ULL

Integrating new technologies in the Fenicia ULL should focus on aligning with the real needs and dynamics of the neighborhood:

1) User-Centered Design: Technologies should be designed with user experience in mind, addressing the practical needs of the neighborhood. This approach ensures that innovations are accessible and usable by the community, fostering higher engagement and satisfaction among users.

2) Utilization of Existing Technologies: Leveraging familiar technologies, such as WhatsApp, can facilitate easier adoption by residents. Utilizing tools that the community is already comfortable with minimizes the learning curve and enhances overall engagement and participation in ULL activities.

3) Adapted Innovation: Aligning technological innovation with the unique dynamics of the urban environment is crucial. This focus on developing practical and usable solutions ensures that new technologies integrate seamlessly into the everyday lives of residents, promoting sustainability and efficiency in urban living.

By prioritizing a human-centric, design-driven approach, the Fenicia ULL can ensure that new technologies align with the practical needs of the neighborhood, making them both accessible and usable for the community. Utilizing existing, familiar technologies such as WhatsApp can significantly enhance the adoption process and engagement levels, reducing barriers to participation and fostering a more inclusive environment. Furthermore, adapting innovations to fit the unique dynamics of the urban environment ensures that these solutions are practical and seamlessly integrate into daily life [1,23], thereby promoting a more efficient and sustainable urban setting. Collectively, these strategies will enable the Fenicia ULL to effectively leverage technology to enhance urban living while maintaining strong community involvement and support, in line with the vision of augmenting urban intelligence and fostering collaborative innovation.

OPERATIONAL LAYER

A. Governance framework proposed for Fenicia ULL

Authors proposed the structure for government of Fenicia ULL that is based on different authors [24-27] and on empirical research from multiple living labs. Figure 1 shows a first model that is based on the roles of: coordinators, creators, enablers,

providers and users. The roles may be played by one or several actors (government, academia, productive and community) depending on the activities carried out in the ULL.

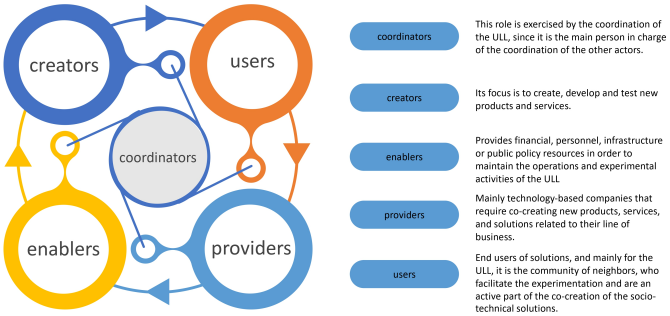

Fig. 2 Governance framework proposed for Fenicia ULL.

B. Methodology framework to socio-technical innovation management for Fenicia ULL

The operation of ULLs requires a comprehensive methodology that integrates key components to ensure their effectiveness and alignment with transformative urban goals. This methodology as shown in Figure 3 is structured around two primary components: Achievement of ULL Objectives and Methods for Socio-Technical Innovations, both of which are interconnected through feedback loops to facilitate continuous improvement and adaptive learning.

The Achievement of ULL Objectives component focuses on meeting predefined Key Performance Indicators (KPIs), which serve as measurable benchmarks for the success of ULL initiatives and attaining three key objectives that define the success of ULL initiatives: *Quality of life* enhancing the well-being and livability of urban environments by addressing social, environmental, and economic challenges; *Productivity* driving economic growth and efficiency by fostering innovative practices and leveraging urban resources effectively; and *ICT-based sustainability* promoting sustainable urban development through the integration of Information and Communication Technologies (ICTs) to optimize resource use, reduce environmental impacts, and create smart, resilient cities. This component is shaped by two influential factors:

1) Drivers: A dynamic analysis of political, economic, social, technological, legal, and environmental (PESTLE) elements, alongside emerging business opportunities, community needs, and urban challenges, provides critical inputs for defining the scope and direction of the ULL.

2) Governance Framework: A participatory governance structure designed to empower stakeholders—academia, industry, government, and the community—to actively engage in the ULL process. This framework encourages stakeholders to participate in decision-making, experiment with innovative solutions, and learn from real-world implementations, fostering an inclusive and collaborative innovation environment.

The second component, Methods for Socio-Technical Innovations, is dedicated to fostering innovative solutions that integrate social and technical dimensions. This process focuses on co-creation, experimentation, and the implementation of transformative innovations that address urban challenges and contribute to sustainable development.

A feedback loop between these components ensures that the outputs of socio-technical innovation—namely transformative solutions—are iteratively evaluated against the KPIs and objectives of the ULL. This iterative process allows for adjustments to the methods and strategies employed, enabling the ULL to remain adaptive and responsive to evolving urban needs.

By leveraging this interconnected methodology, ULLs can effectively balance innovation with measurable outcomes, fostering sustainable, inclusive, and impactful transformations within urban ecosystems.

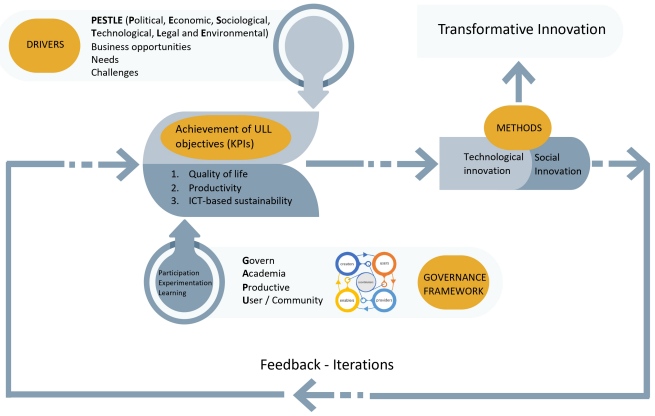

Fig. 3 Methodology framework to socio-technical innovation management.

To ensure alignment between the ULL's strategic objectives and its operational performance, we define a set of Key Performance Indicators (KPIs) corresponding to the three core goals of the framework: Quality of Life, Productivity, and ICT-based Sustainability. Table III summarizes how each KPI contributes to one or more of these objectives. For instance, the citizen engagement rate measures the depth and frequency of community participation, directly reflecting improvements in local agency and well-being. The operational efficiency of the digital twin platform ensures that smart technologies support agile and informed decision-making, thus enhancing productivity and sustainability. The stakeholder integration index evaluates how effectively the ULL mobilizes diverse actors—government, academia, private sector, and community—fostering collaborative governance. Meanwhile, sustainability outcomes, such as reductions in waste or improved energy flows, serve as direct indicators of environmental performance. Finally, the adoption of co-created solutions demonstrates the practical utility and institutional uptake of innovations emerging from the ULL, bridging community relevance with systemic change.

TABLE III
ALIGNMENT BETWEEN PROPOSED KPIS AND STRATEGIC OBJECTIVES OF THE ULL METHODOLOGY FRAMEWORK

Key Performance Indicator (KPI)	Quality of Life	Productivity	ICT-based Sustainability
Citizen engagement rate (e.g., participation in workshops and digital platforms)	✓		
Operational efficiency of the digital twin platform (e.g., update frequency)		✓	✓
Stakeholder integration index (e.g., diversity and coordination among actors)			✓
Sustainability outcomes (e.g., reduction in waste, improved energy use)			✓
Use of co-created solutions (e.g., adoption by local government or private actors)	✓	✓	

V. DISCUSSION AND CONCLUSION

The proposed socio-technical innovation management model in ULLs demonstrates significant potential in addressing urban challenges through the integration of community engagement, governance structures, and technological solutions. The findings reveal that the strategic framework fosters dynamic collaboration among stakeholders, enabling iterative development and localized adaptation of innovations. By anchoring solutions within real world contexts, the model enhances their relevance and sustainability, aligning well with the principles of participatory urban development.

The implementation of the model underscores the importance of enhancing civic engagement as a foundational element. Active participation by citizens not only enriches the co-creation process but also ensures that the developed solutions resonate with community needs and preferences. This aligns with existing literature emphasizing the pivotal role of user-centric approaches in ULLs. Furthermore, the iterative testing of technologies in controlled environments, such as digital twin platforms, highlights the value of real time feedback mechanisms for refining and scaling innovations.

Despite these advancements, several challenges persist. The resistance to adopting new governance frameworks and the fragmentation among stakeholders were significant barriers encountered during implementation. These issues emphasize the need for robust governance structures that can harmonize diverse perspectives and align stakeholder priorities. Additionally, the integration of socio-technical strategies revealed gaps in addressing the contextual complexities of developing countries, particularly in regions with limited access to digital infrastructure and technical expertise.

International comparisons with ULL initiatives in cities such as Helsinki and Eindhoven validate the effectiveness of adopting participatory and iterative frameworks. However, the model's contextual adaptation to the Fenicia Urban Living Lab in Bogotá highlights unique contributions to the nexus of waste, energy, and information management. By leveraging digital twins and fostering community involvement, the model bridges the gap between theoretical innovation strategies and practical urban interventions, creating pathways for sustainable development.

While the model has been designed with adaptability in mind, its scalability to other urban contexts requires careful consideration of local socio-economic and political conditions. Cities with different governance structures, degrees of decentralization, or levels of institutional maturity may face unique challenges when adopting the proposed framework. Key factors that influence scalability include the presence of enabling governance mechanisms, the availability of technical infrastructure for digital twin deployment, and the degree of institutionalized civic participation. In cities where stakeholder trust is low or where top-down governance prevails, participatory co-creation processes may need to be introduced incrementally. Moreover, technological limitations—such as restricted access to real time urban data—may require adaptations in the scope or functionality of digital tools. Therefore, while the model provides a robust foundation for innovation management in ULLs, its effective transfer demands contextual calibration and capacity-building efforts tailored to each city's specific realities.

The insights derived from this research contribute significantly to the discourse on smart cities and sustainable urban innovation. The proposed framework not only advances the understanding of socio-technical integration but also provides a replicable model for other developing regions. By prioritizing inclusivity and sustainability, the study aligns with global objectives such as the United Nations' Sustainable Development Goals, particularly Goal 11, which emphasizes inclusive, safe, resilient, and sustainable cities.

In conclusion, the socio-technical innovation management model represents a critical advancement in the operationalization of ULLs. By integrating community-driven approaches, governance, and technological solutions, it lays the groundwork for transformative urban practices. Future research should focus on expanding the scalability of the model, exploring its application in varied urban contexts, and developing comprehensive metrics for evaluating its social and environmental impacts. These efforts will ensure that ULLs continue to serve as pivotal platforms for fostering innovation and achieving sustainable urban growth.

A. Limitations and Contextual Risks.

Despite its comprehensive design, the proposed innovation management model presents several limitations and risks when applied beyond the Fenicia case. First, the model relies on the availability of digital infrastructure, which may not be uniformly accessible in all urban contexts particularly in low resource settings. Second, institutional resistance may arise in

cities where participatory governance and co-creation are not culturally or politically embedded, limiting stakeholder alignment and adoption. Third, cultural norms and trust dynamics may hinder meaningful community engagement, especially in societies with limited traditions of civic participation. Lastly, high turnover in public administration or political instability can undermine the continuity of innovation processes, particularly when long term implementation and institutional learning are essential. Acknowledging these risks is critical to inform future adaptations of the model and to develop strategies that anticipate local constraints.

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