

Bridging Sustainability Realms: A Thematic Synthesis of Sustainable Living Labs

Nasim Molany¹, Rahinah Ibrahim^{1*}, Nik Fazlysham Nik Mat¹

¹Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

* Corresponding Author: rahinah@upm.edu.my

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Abstract: *This review paper aims to shed light on the concept of sustainable living labs by reviewing earlier studies on the subject. Within the discipline of architecture, academic research has witnessed a noticeable surge of interest in sustainable living and living labs since the early 2000s. However, the body of literature on these two subjects remains limited in quantity. To comprehend this gap, the present review article examines a collection of 41 articles, published between 2014 and 2023 obtained from journals in Scopus, Google Scholar, and Science Direct focused on architecture, innovation, and sustainability. This research explores diverse topics in sustainable living labs focusing firstly on university campuses as sustainable living labs, second on innovation in sustainable living labs, third on sustainable living labs to achieve sustainable development goals, and finally on urban sustainable living labs. Additionally, this paper provides a comparative overview of the methodological approaches utilized in the reviewed articles. A gap in the literature has been identified in the integration of sustainable living and living labs as a combined concept, to create research that focuses on the impact of sustainable living labs. Finally, research shows that there is a lack of focus on understanding the impact of such sustainable living labs among specific users such as architectural students, which can add value to the existing body of literature in future studies.*

Keywords: Sustainable Living Lab, Sustainable Development Goals, Innovation in Sustainable Living Lab, Campus Sustainable Living Lab, Urban Sustainable Living Lab

1. Introduction

This literature review focuses on Sustainable Living Labs (SLLs) from 2014 to 2023, exploring their transformative potential across diverse domains. Encompassing topics like university campus living labs, innovation, and urban living labs, the selected articles touch on multidisciplinary aspects. Concepts such as community engagement, stakeholder management, and SLL establishment within fields like long-term care, architecture, waste management, sustainable tourism, and renewable energy are briefly discussed. The primary aim is to synthesize SLL usage contexts, identifying key themes, insights, and best practices while addressing gaps in the current literature. The review provides valuable insights for researchers, practitioners, and stakeholders interested in SLLs and their role in advancing sustainability.

Research Objectives

- i. RO1. Explore the Concept of Sustainable Living Labs: Examine the main characteristics of sustainable living labs as platforms for fostering sustainable practice.
- ii. RO2. Investigate the Contribution of Sustainable Living Labs in Fostering Innovation: Analyze how sustainable living labs facilitate innovation for enhancing innovation sustainability.
- iii. RO3. Investigate the Contribution of Sustainable Living Labs in Campus Environments: Analyze the role of sustainable living labs in campus settings, including universities and educational institutions for enhancing educational sustainability.
- iv. RO4. Investigate the Contribution of Sustainable Living Labs in Urban Contexts: Analyze the role of sustainable living labs in shaping urban planning, resource management, and community engagement for enhancing urban sustainability.
- v. RO5. Investigate the Contribution of Sustainable Living Labs towards Sustainable Development Goals (SDGs): Analyze the alignment of sustainable living labs with achieving specific Sustainable Development Goals (SDGs) outlined by the United Nations, thereby enhancing global sustainability.

Sustainable Living Labs

The SLLs are collaborative platforms addressing sustainability challenges through research and experimentation. These labs, whether real or virtual, bring together diverse stakeholders for innovative problem-solving. The review delves into existing literature, revealing variations in terminology such as "Urban Living Labs" (ULLs) for urban sustainability focus and "Campus living labs" for university-based SLLs. The nuanced exploration of terminologies enriches our understanding of SLLs and their diverse applications.

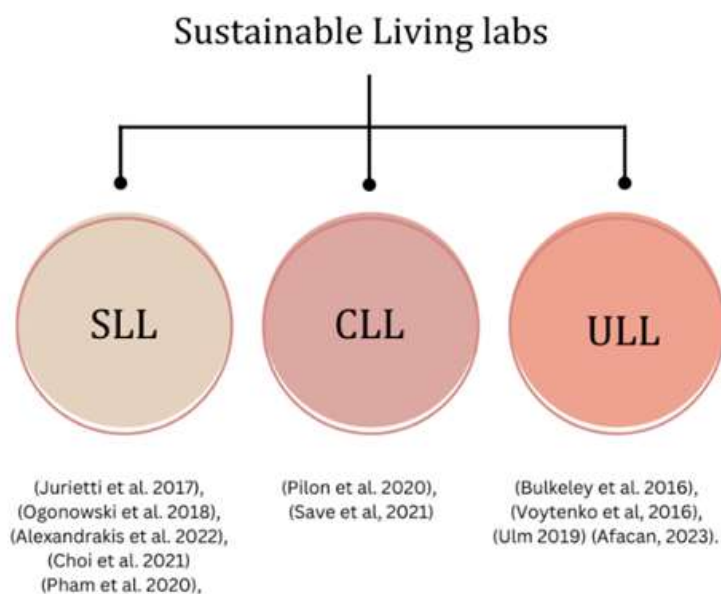


Figure 1: Sustainable Living Lab Terminologies

2. Research Method

This section includes a comprehensive overview of the methodological approach employed to conduct this thematic literature review investigating the role of sustainable living labs in promoting sustainability outlined in Figure 2. The review aimed to uncover and synthesize key themes associated with the integration of sustainable living labs, innovation, campus environments, urban contexts, and sustainable development goals.

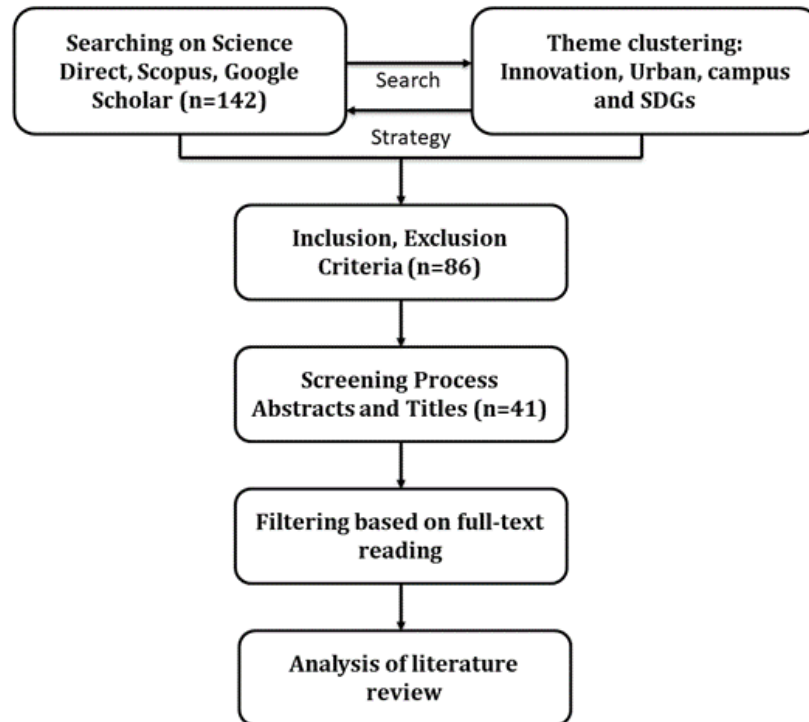


Figure 2: Review Method Flowchart

Search Strategy

A comprehensive search strategy identified relevant literature on sustainable living labs' impact on sustainability using Science Direct, Scopus, and Google Scholar. Keywords like "Sustainable living lab," "sustainable development goals," "Innovation in the sustainable living lab," "Campus sustainable living lab," and "urban sustainable living lab" were employed with Boolean operators for refinement.

Inclusion and Exclusion Criteria

Inclusive criteria encompassed articles focusing on sustainable living labs, innovation, campuses, urban settings, and sustainable development goals published in English between 2014 and 2023. A diverse set of sources, including peer-reviewed articles, conference papers, reports, book chapters, and reputable theses, were considered. Irrelevant studies or those lacking substantial discussions were excluded, resulting in a final dataset of 41 articles for analysis.

Screening Process

Initial screening was performed based on the titles of articles and abstracts of all 86 sources to remove irrelevant articles. Each source was investigated to judge its relevance to the research objectives mentioned earlier: 1. Role of SLLs in promoting sustainability, 2. How these labs contribute to innovation, campus environments, urban settings and the achievement of SDGs. Irrelevant articles or those not demonstrating a straightforward alignment with the research objectives were marked for exclusion.

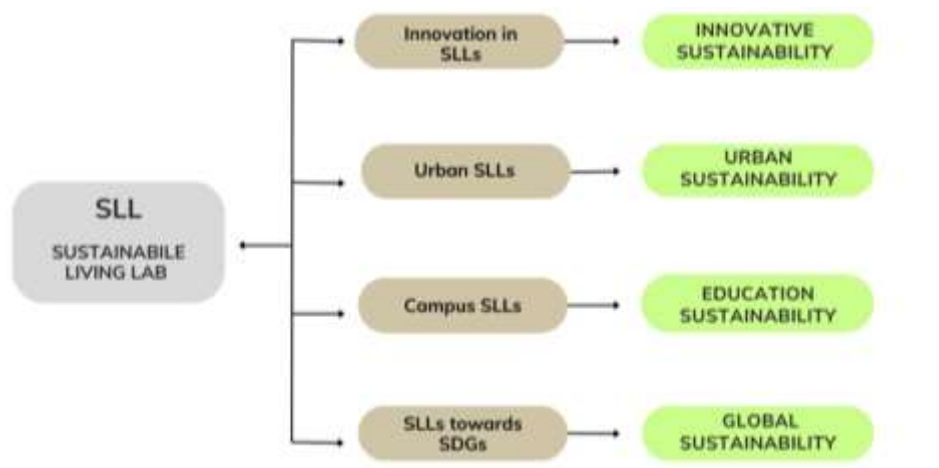


Figure 3: Literature Review Themes

3. Literature Themes Analysis

In recent years, sustainable living labs have gained prominence in environmental sustainability and urban planning. This literature review explores 41 selected articles to provide a structured overview of key themes. Table 1 outlines study objectives, geographical contexts, and years. Our goal is to contribute to a deeper understanding of sustainable living labs and their role in shaping a more sustainable future.

3.1 Campuses as Sustainable Living Labs

University campuses are transforming into Sustainable Living Labs (SLLs), fostering innovation and sustainability. This review of seven studies examines SLLs on campuses, highlighting their focus, methods, findings, and limitations. While showcasing benefits, these studies often lack concrete examples, long-term sustainability strategies, and comprehensive coverage of sustainability dimensions. A holistic approach is essential for a sustainable future.

Table 1: Comparative Matrix: Campuses as Sustainable Living Labs

No.	Study	Objective	Methods	Main Findings	Strengths	limitations
1	Evans et al. (2015)	Framework for collaborative knowledge	Qualitative (interviews, case study)	University Living Lab fosters collaboration	In-depth case study co-production framework	Lack of concrete examples of successful projects
2	Verbeek et al. (2020)	Interdisciplinary collaboration	Descriptive analysis, case studies	Living Lab in Ageing" enhances care quality	Insights into Interdisciplinary Partnerships	Limited discussion on long-term sustainability strategies
3	Pham et al. (2020)	Smart universities framework	Qualitative (analysis, pilot projects)	Smart universities as SLLs for innovation	Comprehensive analysis of the smart university concept	Focus on technical aspects, need for long-term strategies
4	Pilon et al. (2020)	Cultivating a culture of research	Case study analysis	Campus Living Lab enhances educational exp	Concrete examples of CLL initiatives	Limited scalability and generalizability concerns.
5	Save et al. (2021)	Formalizing campus SLL program	Ethnographic approach	Operationalizing CLL for sustainability	Detailed process models, actionable insights	Limited external applicability and scalability.

6	Martek et al. (2022)	University sustainability office	Quantitative, case study analysis	Coordinated approach for SLL success	Replicable processes, organizational charts	Limited central coordination and scalability.
7	Trombador e & Calcagno (2022)	Med-Eco SuRe project in the Mediterranean university	case studies approach	Energy renovation through Living Lab	Combining Living Lab and Digital Twin principles	Limited contextual generalization potential.

3.2 Innovation in Sustainable Living Labs

This review explores Sustainable Living Labs (SLLs) as catalysts for sustainability innovation. Studies by Schuurman et al. (2016) and Haider et al. (2016) emphasize open innovation and broader understanding. Gatta et al. (2018) focus on stakeholder behavior change, while Mačiulienė and Skaržauskienė (2020) address digital co-creation. Baran and Berkowicz (2020) propose a cultural sustainability model, and Alexandrakis et al. (2022) explore SME integration. Campos and González (2023) investigate Responsible Innovation in renewable energy. Maruyama et al. (2023) scrutinize sustainability at Sophia University. It is apparent from these studies that despite their role in fostering innovation, SLLs have limitations, including a narrow focus and potential biases. Future research should adopt comprehensive methodologies for a nuanced understanding of SLLs' impact on sustainability.

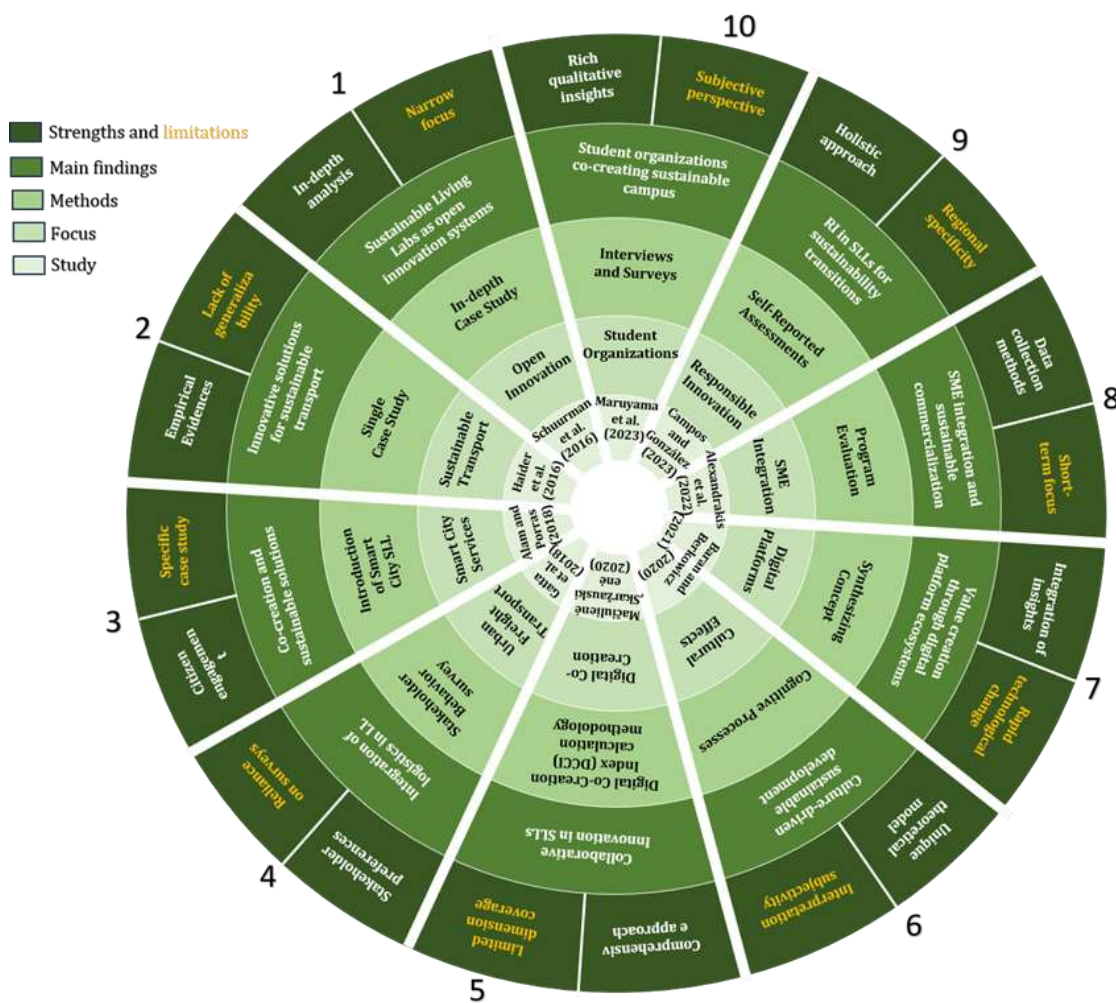


Figure 4: Innovation in SLL synthesis summary

Figure 4 illustrates that SLLs drive innovation through stakeholder engagement and sustainable solutions, but limitations such as narrow case studies and methodological biases exist. Further research is required for a comprehensive understanding of SLLs' impacts on innovation and sustainability.

3.3 Urban Sustainable Living Labs:

Urban Sustainable Living Labs (ULLs) play a vital role in addressing urban challenges and fostering sustainable development. Studies by Bulkeley et al. (2016) and Voytenko et al. (2016) highlight their contributions, emphasizing the need for research into stakeholder perspectives and attractiveness in urban settings. Ulm (2019) showcases the positive impact of the Permaculture Living Lab on urban agriculture and community connections. Yang and Yoo (2021) stress the importance of studying specialized ULLs, like "Startup Living Lab", for their impact on professional communities. Günther et al. (2023) provide insights into citizen perspectives on ULLs, focusing on sustainable mobility. Afacan (2023) explores ULLs' transformative role in designing inclusive urban environments. The limitations in these studies such as small sample sizes and lack of focus on specific stakeholder needs bring along the necessity for more extensive research to fully understand their potential in sustainable urban development.

Table 2: Comparative Matrix: Urban Sustainable Living Labs

No	Study	Objective	Methods	Main Findings	Strengths	limitations
1	Bulkeley et al., 2016	Role of ULLs in sustainability goals	Literature review	Urban Living Labs (ULLs) contribute to urban sustainability goals, addressing power dynamics in urban interventions.	Recognizes the role of power dynamics in ULLs and their potential for governing urban development	Lack of focus on specific stakeholder needs
2	Voytenko et al., 2016	ULLs in urban governance	Literature review, case studies	Urban Living Labs (ULLs) represents a new approach to urban governance for sustainability, requiring further exploration	Compares literature and case studies to understand ULLs' role in urban governance.	More investigation is needed into stakeholder perceptions of ULLs.
3	Ulm, 2019	ULLs for sustainable urban agriculture	Case study, empirical results	Permaculture Living Lab (PermaLab) serves as a platform for sustainable urban agriculture, enhancing collaboration and research.	Focuses on a specific type of ULL and highlights its role in urban agriculture	Narrow focus on a specific lab: PermaLab. Lacks comparison with other ULLs
4	Yang & Yoo, 2021	ULLs' impact on professional groups	Case study	"Startup Living Lab" engages young architects, improving urban regeneration projects, and highlighting the importance of specialized SLLs.	Analyze the impact of specialized SLLs on professional groups, as architects	Limited consideration of alternative perspectives.
5	Günther et al., 2023	Citizen perspective on ULL effectiveness	Survey	ULLs enhance citizen awareness of sustainable mobility and urban transformation, with a specialized focus on citizen perspective.	Specialized insight from a citizen perspective, and practical insights for ULL design and evaluation.	A small sample size may limit the generalizability of findings

6	Afacan, 2023	ULLs for sustainable urban design	Case study	ULLs, as SLLs, contribute to knowledge exchange and innovative solutions in sustainable urban design and land use policies	Integrating ULL approach into the graduate design studio shows improvements in knowledge exchange.	Single implementation in a graduate design studio might not reflect real-world ULL complexities
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3.4 Sustainable Living Labs Towards Sustainable Development Goals:

The literature on sustainable living labs (SLLs) in relation to achieving sustainable development goals (SDGs) encompasses various studies offering insights into their potential and limitations. Purcell et al. (2019) investigate SLLs within universities, acknowledging their transformative potential but critiquing the lack of comprehensive examination of obstacles. Verbeek et al. (2020) focus on a specific SLL in aging and long-term care, stressing partnership importance, although neglecting to thoroughly explore challenges at the university level. Turi et al. (2021) address educational aspects of SDGs with SLLs, highlighting real-world experimentation but lacking in-depth examination of sustainability issues. Rukspollmuang (2022) proposes an SDG integration model through SLLs, emphasizing multidisciplinary collaboration but lacking the consideration of implementation difficulties. Bouma and Veerman (2022) explore SLLs for soil health, directed towards bridging research and practice. Their work however does not address applicability across diverse contexts. Mazutti et al. (2020) focus on a smart and learning campus, highlighting air quality monitoring but their research demonstrates a limited understanding of overall sustainability challenges. Choi et al. (2021) and Alexandrakis (2021) accentuate SLLs' participatory attribute in achieving SDGs through digital innovations. The potential difficulties and stakeholder obstacles in their work are not methodically explored. Compagnucci et al. (2021) examine SLLs in the Quadruple Helix Model, providing insights into stakeholder engagement but potentially overlooking larger systemic issues related to UN SDGs. While these studies underscore SLLs' transformative potential in contributing to SDGs, their limitations underscore the need for a more comprehensive understanding of their role in addressing complex systemic issues. Each study offers valuable perspectives, but a critical synthesis is necessary to advance the discourse on SLLs and sustainable development goals.

Table 3: Sustainable Living Labs towards Sustainable Development Goals

No	Study	Objective	Methods	Main Findings	Strengths	limitations
1	Purcell et al. (2019)	Role of sustainable Living Labs in working towards SDGs within Universities	Multiple-case study approach	SLLs have innovative leadership roles contributing to SDGs	Utilizes a comprehensive methodology	Lacks potential obstacles in implementation
2	Verbeek et al. (2020)	"Living Lab in Ageing and Long-Term Care" at Maastricht University as an efficacious SLL for achieving SDGs	Descriptive analysis, case studies, qualitative interviews	ULLs like "Living Lab in Ageing and Long-Term Care" contribute to SDGs through societal advancements and enhanced quality of life	Highlights partnerships and leadership roles	Lacks potential obstacles in implementation : e.g., resource limitations and resistance to change
3	Turi et al. (2021)	Role of learning factories in SLLs and their integration with SDGs	Systematic Research Review	SLLs integrate real-world experimentation, research, and innovation aligned with SDGs	Recognizes the necessity of stakeholder cooperation	Limited depth of analysis and empirical data

4	Rukspollmuang (2022)	Integration of SDGs into academic, research, and engagement activities through SLLs	Mixed Methods Document Research and Questionnaire	SLLs have transformative potential in achieving SDGs through co-creating research and innovations	Reiterates the importance of SLLs in achieving SDGs	Lacks discussing challenges in applying the suggested model
5	Bouma & Veerman (2022)	Use of SLLs as platforms for scientists and farmers to develop innovative methods for soil health aligned with SDGs	primarily quantitative Integrated assessment	SLLs bridge the gap between research and practice in soil health management, aligned with SDGs	Focuses on practical implementation and innovation	Lacks discussing the applicability of suggested indicators and techniques
6	Mazutti et al. (2020)	Integration of smart technologies and learning environment within the smart and learning campus for achieving SDGs	Case Study Analysis	SLLs like Smart and Learning Campus facilitate innovative solutions for addressing sustainability challenges, focusing on air quality monitoring	Incorporates smart technologies for sustainable development in universities	Limited scope applicability beyond university campuses.
7	Choi et al. (2021)	The participatory attribute of SLLs in co-creating sustainable solutions and their domain of impact (modelling and simulation vs. urban design)	Modeling and Simulation	SLLs' participatory nature and digital innovations contribute to co-creating sustainable solutions	Emphasizes the participatory aspect of SLLs	Lacks elements impacting sustainability transitions or difficulties faced by stakeholders in SLLs
8	Alexandrakis (2021)	Analyze Urban Design Thinking's impact on accelerating urban sustainability transitions via Sustainable Living Labs.	Urban Design Thinking	Urban Design Thinking in Sustainable Living Labs enhances co-creation, knowledge generation, and accelerates urban sustainability transitions through Sustainable Product-Service Systems (SPSS).	UDT enhances SLL co-creation.	Limited user engagement, applicability.
9	Compagnucci et al. (2021)	Role of SLLs in promoting innovation and sustainability within the Quadruple Helix Model (QHM) and their contribution to UN SDGs	Multiple-case study approach	SLLs involve users in co-creating value and innovation, which contributes to sustainability and SDGs within the QHM framework	Provides guidance for establishing SLLs	need for broader and quantitative analysis of SLLs.

4. Sustainable Living Lab Synthesis

Despite extensive research on sustainability, living labs, and Sustainable Living Labs (SLLs) from 2014 to 2023, there is limited data specifically addressing their effects. Positive impacts are noted on sustainable development goals and innovation, especially in university campuses and urban sustainability. Studies mainly concentrate on implementing SLLs in universities, utilizing experiments, case studies, and surveys. However, there's a gap in exploring SLLs as

living spaces or student hostels for innovative sustainable learning experiences. Surprisingly, there are no specific review papers addressing sustainable living labs' integration into both work and living environments, a gap in existing broader reviews. In 2021 and 2022, a notable increase in papers indicates progress in SLL research, but most focus on developmental aspects, leaving crucial areas like students, health, food, and climate with limited research. Future scholars are urged to comprehensively investigate the impact of sustainable living labs to fill these knowledge gaps.

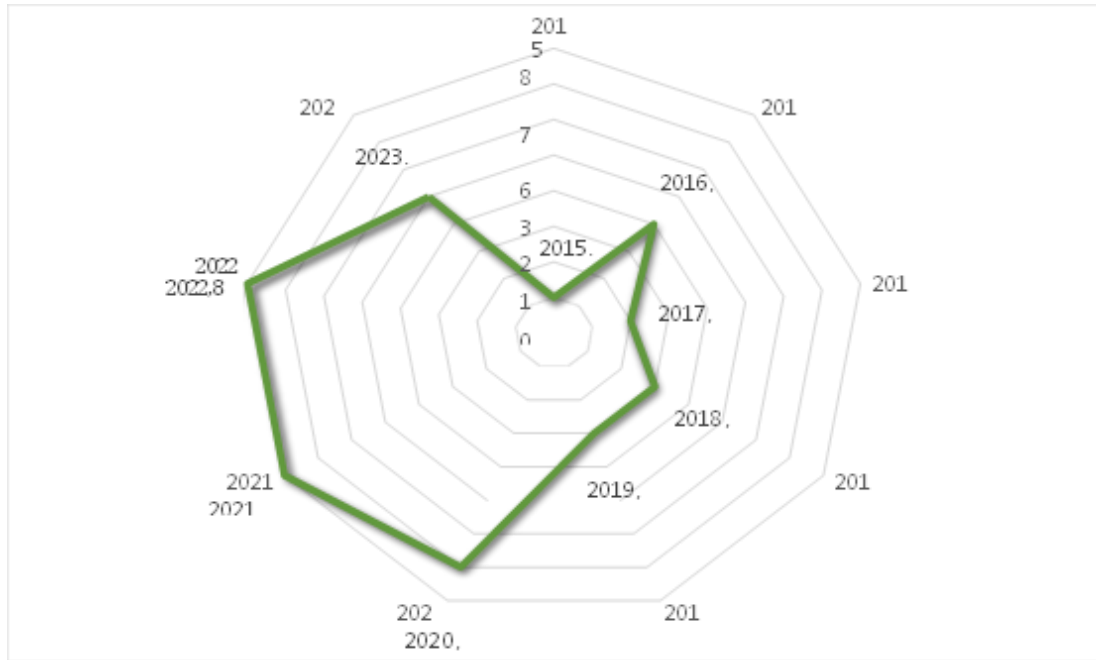


Figure 5: Sustainable Living Lab Articles based on Year

In 2022 and 2023, there's a noticeable increase in scholarly publications on sustainable living labs, mainly focusing on theoretical frameworks related to university campuses, sustainable development goals, urban sustainability, and innovations. However, critical areas like students' well-being, healthcare, nourishment, and climate, initially central to the concept of sustainable living labs, receive minimal scholarly attention.

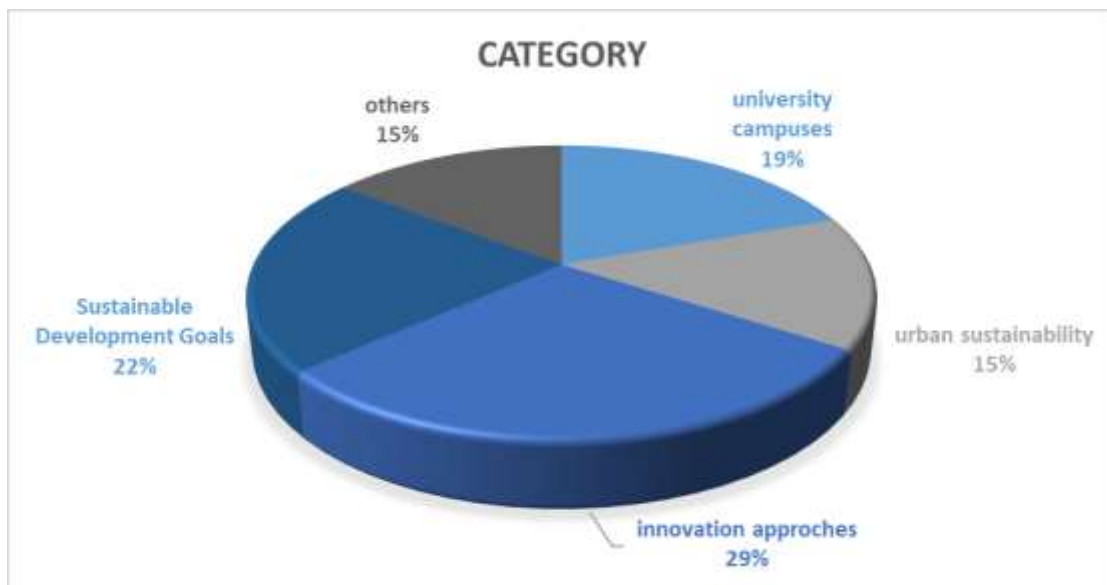


Figure 6: Categories of Sustainable Living lab

5. Conclusion

The review of studies reveals the rising prominence of Sustainable Living Labs (SLLs) and their role in transforming university campuses into real-world sustainability testing grounds. These living labs, particularly Urban Living Labs (ULLs), provide collaborative platforms where various stakeholders address urban issues. SLLs and ULLs showcase strengths in co-creating value, encouraging interdisciplinary work, and aligning with Sustainable Development Goals (SDGs). They contribute to practical solutions for sustainability challenges, including urban resilience and sustainable transportation awareness. However, limitations include a lack of specific project illustrations, insufficient consideration of broader sustainability issues, and potential biases in some studies. To address these constraints, future research should adopt a more comprehensive and varied approach, exploring various sustainability dimensions, stakeholder perspectives, and long-term impacts on innovation and the environment. Concrete case studies and data-driven analyses are recommended for a more effective and impactful contribution to sustainability and SDGs.

6. Suggestions and Discussion

Sustainable living labs, and collaborative spaces for sustainability research, are gaining popularity. However, addressing limitations is crucial for their long-term viability. Emphasizing long-term impacts, incorporating cutting-edge technologies, and focusing on future sustainability is essential. Adopting a sustainable lifestyle is key for instilling principles and addressing environmental challenges. Solutions include continuous impact assessments, technological integration, and extending labs to more institutions. To enhance understanding and maximize impact, the development of a comprehensive model showcasing the specific environmental and global challenges addressed by SLL initiatives is recommended. Despite limitations, sustainable living labs hold promise as vibrant hubs for promoting a sustainable future and addressing global warming.

7. Contributions of Study

The study provides valuable insights from various articles on sustainable living labs, offering future scholars a foundation to enhance their design efforts and propose relevant frameworks based on identified gaps. These insights contribute to the advancement of innovative designs and solutions across diverse fields. The comprehensive literature review establishes a strong knowledge base, empowering future scholars to create impactful research designs and conduct empirical studies. Additionally, the study emphasizes that the sustainable living lab, merging living lab and sustainable living concepts, is a relatively new concept with identified gaps to address in architecture, industry, and beyond.

8. Future studies

Future studies can focus on the concept of a sustainable living lab as a comprehensive platform that includes a sustainable living environment deeply engrained in the lifestyle of the users while also being a sustainable lab for experimenting and co-creating sustainable solutions in various technical fields. These studies can aim to elevate the level of sustainability within the sustainable living lab (SLL) and explore innovative approaches for implementing it in various contexts. Additionally, there is potential to utilize the SLL concept as a contemporary hostel customized for students from specific fields such as architecture, engineering, and business.

This would create a unique learning environment where students can immerse themselves in sustainability-related practices specific to their respective fields.

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