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Review

Urban Living Labs: A Higher Education Approach to Teaching and Learning about Sustainable Development

Ivetheyamel Morales [1,2,*], Jordi Segalás [3] and Torsten Masseck [4]

[1] School of Architecture and Urbanism, University of Guayaquil, Guayaquil 090510, Ecuador
[2] Doctoral Programme in Sustainability, Universitat Politècnica de Catalunya UPC, 08034 Barcelona, Spain
[3] Research Institute for Sustainability Science and Technology, Universitat Politècnica de Catalunya UPC, 08034 Barcelona, Spain; jordi.segalas@upc.edu
[4] Department of Architectural Technology, Universitat Politècnica de Catalunya UPC, 08034 Barcelona, Spain; torsten.masseck@upc.edu
* Correspondence: ivetheyamel.moralesv@ug.edu.ec

Abstract: This study focuses on the use of urban living labs (ULLs) as a teaching and learning strategy toward education for sustainable development (ESD) in higher education institutions (HEIs). The article presents an exhaustive literature review on the ESD approach in HEIs, the conceptualization and understanding of ULLs, and the use of ULLs as learning environments. Several ULL case studies in HEIs that seek to foster ESD through innovation and experimentation in real-world settings are presented. Each case describes the type, approach, characteristics, results, limitations, and challenges in relation to sustainability. It highlights the need for HEIs to adapt to the ESD approach and become role models for sustainability. It is concluded that ULLs are closely related to ESD and the SDGs, provide a practical and applied learning environment for students, encourage the active participation of students in identifying and solving sustainability problems in their local community, and encourage interdisciplinary collaboration between students and academics from different disciplines. All in all, ULLs can be an effective teaching and learning strategy in HEIs toward ESD. In addition, the lack of specific empirical results on the evaluation of ULL as teaching and learning tools toward ESD in HEIs is highlighted, which justifies the need for further research in this field.

Keywords: sustainable development (SD); education for sustainable development (ESD); urban living labs (ULLs); institutes of higher education (HEIs); teaching and learning strategies; learning environments; scenarios for teaching and learning; sustainability competencies; institutional capacities; learning in the real world

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1. Introduction

Education is an essential tool for achieving the comprehensive sustainable development of society. UNESCO's recognition of education as one of the seventeen Sustainable Development Goals (SDGs) of the 2030 Agenda highlights its paramount significance. SDG 4 aims to guarantee inclusive, equitable and high-quality education while fostering continuous learning prospects for everyone. A closer look at SDG 4 target 4.4 underscores its significance by emphasizing the imperative of equipping all learners with the knowledge and competencies necessary to advance sustainable development. There are several aspects involved in this process, including the promotion of sustainable development through education, the acceptance of sustainable living, the advocacy for human rights, the promotion of gender equality, the promotion of peace and nonviolence, the promotion of global citizenship, and recognition of the value of cultural diversity in advancing sustainable development [1].

In addition, sustainability is one of the key education and training priorities of the European Commission for the period 2019–2024. Sustainability education aims to provide students with sustainability competences to reflect and embrace sustainability in their

daily lives, playing many roles, including learning, consuming, creating, advocating, influencing policy, and contributing to the betterment of organizations, communities, and society at large [2]. Global challenges are of prime concern to higher education institutions (HEIs), and education plays a crucial role in preparing people to handle responsibilities, enabling them to contribute to sustainable development and participate actively in it [3]. The role of the university in society is diverse; it researches, innovates, generates and transfers knowledge, and interacts with the community; one of its objectives is to train responsible professionals who are sensitive to the new demands of the community and the planet. In this transformative path, higher education institutions must not only change towards a model of education for sustainability but also become models of sustainability in practice [4,5]. Fundamentally, HEIs that can align their institutional capacities with the 2030 SDG targets and foster a culture of collaboration will be better equipped to meet their own challenges. This is how the university will evolve into a transformative institution that engages in collaborative activities within the knowledge-driven economy. In these universities, students are at the center of the educational process, and collaboration with external agents and society in general is actively encouraged [6].

In this quest to fulfill the relevant role of HEIs in meeting sustainability challenges, living labs (LLs) appear as one of the emerging strategies. LLs are dynamic spaces where innovation and experimentation thrive; they work as laboratories where teaching and learning tools that enable the reproduction of knowledge in different contexts and at different scales are used. These laboratories enable universities to address sustainability challenges [7].

ULLs are part of LLs and emerge as a platform for collaborative urban experimentation and governance, addressing sustainability challenges and opportunities in cities. LLs and ULLs differ mainly in their focus and scope. LLs typically focus on innovation at the product or service level, whereas ULLs focus on innovation at the city or community level, addressing broader urban challenges such as sustainability, mobility, or social inclusion. In addition, ULL solutions often involve a higher degree of citizen participation and collaboration between different sectors and stakeholders [8–10].

This study strives to analyze research that encompasses the nexus between ULLs and ESD within HEIs and the advantages and disadvantages associated with this learning environment in HEIs. To achieve this endeavor, it is essential to guide the research through a comprehensive understanding of ESD within HEIs, as well as to further the conceptual exploration of ULLs and their inherent characteristics. The broadening of knowledge on these issues contributes significantly to the analysis of the ULL approach. Analyzing case studies from the point of view of the characteristics of ULLs and their consequences on ESD praxis in HEIs is proposed.

With this background, it is crucial to underscore the primary goal of this study: to examine the ULL approach as a teaching and learning environment in HEIs toward ESD. This research seeks to achieve the following specific objectives:

- To conduct a comprehensive review of ESD within HEIs.
- To achieve a deep conceptual understanding of ULLs and their characteristics.
- To analyze cases in which ULLs have been leveraged as learning environments in HEIs and their intricate relationship with ESD.

The research questions to be answered are the following:

- Is there a link between ULLs and ESD in HEIs?
- What are the advantages and disadvantages of ULLs as a teaching and learning strategy in HEIs toward ESD?

2. Materials and Methods

The theoretical research approach that describes this work is the interpretative hermeneutic approach. Weiss citing Kaplan and Ritsert indicates that hermeneutics aims to elaborate patterns of meaning, to structure them in such a way that they allow us to understand the academic literature, and to construct a configuration of meanings [11]. The

theoretical research technique used is desk-based research, more specifically the exhaustive literature review [12]. The literature review is conducted using the search, appraisal, synthesis, and analysis (SALSA) structure [13], which consists of four stages: search, selection, synthesis, and analysis. The search was carried out using the Google Scholar search engine and the databases and repositories Scopus, Oxford Journals, Web of Science, and UPCommons, using the following keywords in English and Spanish: "Urban AND living AND lab" OR "sustainable AND higher AND education" OR "Urban AND living AND lab OR sustainable AND higher AND education" OR "urban AND living AND labs AND as AND a AND tool AND for AND teaching AND and AND learning AND in AND higher AND education" OR "urban AND living AND labs OR teaching AND and AND learning AND methods" OR "evaluation AND of AND urban AND living AND labs". The selection of the information was carried out through a bibliometric analysis, using Bibliometrix software (version 4.0.0), RStudio (version 2022.07.0) and Vosviewer package (version 1.6.18), considering two criteria: typology and subject of study. The first criterion refers to doctoral theses, master's theses, scientific articles, papers, guides, and reports; the second criterion includes publications on conceptualization and definition of ULLs, EDS in IES, application of ULLs in higher education, and evaluation of ULLs as teaching and learning methods. One hundred and sixty documents were selected for further analysis. Once the selection was made, we proceeded with the synthesis, which consisted of extracting the basic information, such as the title of the publication, the type, where it was published, the authors, the year, the abstract, and the number of citations. We then proceeded to read the abstract to ensure that the focus of the document was relevant to our research. Prioritizing the importance of the publication medium, the number of citations, and the abstract, one hundred and ten documents of interest to the study were compiled. In Figure 1, the applied exhaustive literature review is depicted, following the PRISMA flowchart with its four distinctive phases, leading to the final selection of 110 studies [14–16]. The analysis of the information starts with reading the publications, grouping the topics of interest, and identifying their findings. It is important to keep in mind that not all the articles analyzed are listed in the references; this omission is intentional, as we have chosen to reference only the most recent and highly cited articles when multiple sources share identical or similar findings. Once the process of grouping all the publications and identifying the findings was completed, we proceeded with the synthesis and analysis of the selected information. Three axes were prioritized: the approach to ESD in HEIs, the conceptual understanding of ULLs, and the use of ULLs as learning environments in HEIs toward sustainable development. For the analysis of ULLs as learning environments, four cases of ULLs that presented relevant information were taken. Furthermore, considering that the LLs handle a similar concept to ULLs [17], two LL cases that caught our attention were analyzed. The analysis consisted of determining the type of ULL according to the form of inquiry and what drives it; the approach; the characteristics according to the dimensions of objectives, activities, participants, and context; the results; and the limitations and challenges. A representation of the search, appraisal, synthesis, and analysis (SALSA) structure is shown in Figure 2.

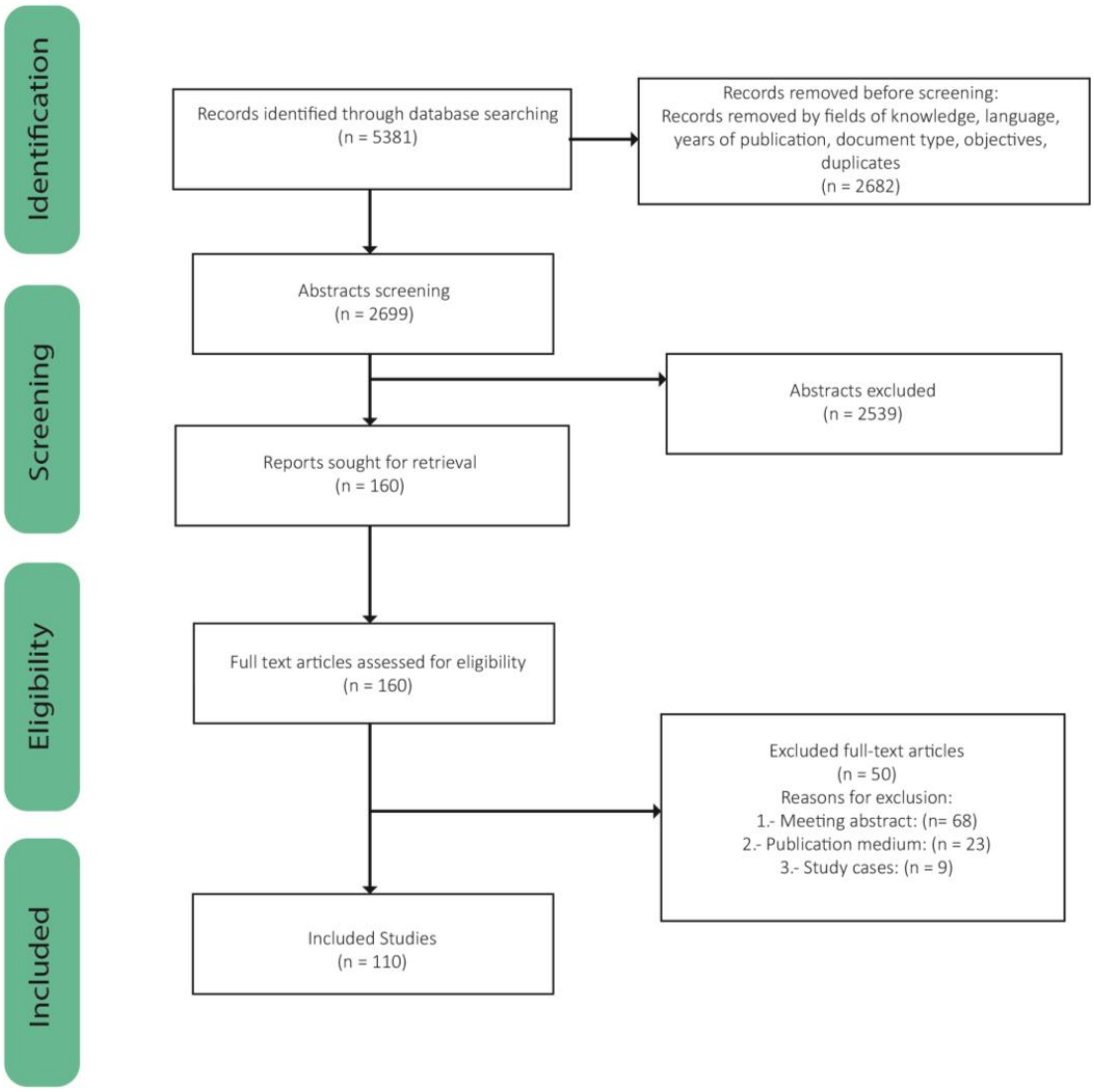

Figure 1. Based on the PRISMA diagram [14].

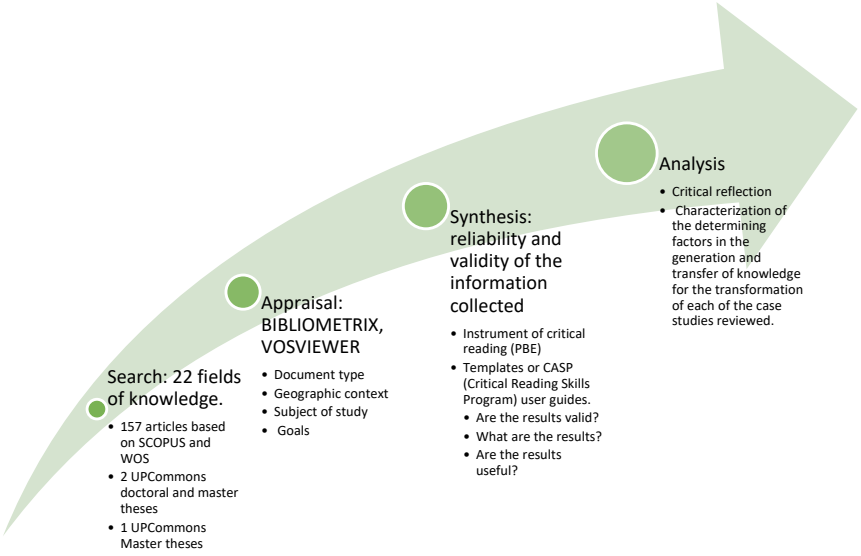

Figure 2. Based on the SALSA (search, appraisal, synthesis, and analysis) structure [13].

3. Results

3.1. ESD Focus in HEIs

By promoting sustainability in higher education, universities can help create a more just and equitable future for all and contribute to the protection of the environment and the conservation of natural resources. HEIs are key institutions in training future leaders and professionals in various fields and therefore have a responsibility to foster sustainable awareness and action in society [18]. One of the great challenges is the transition of HEIs toward SD, having to reorganize and redefine themselves to be effective agents of change in society [19]. Therefore, the big question is what strategies should be put in place to successfully promote sustainability in HEIs? Some authors [6,20,21] stress the importance of addressing education for sustainable development (ESD) in a holistic and collaborative way, involving multiple stakeholders and disciplines to achieve meaningful change toward more sustainable practices; they emphasize the need for a holistic approach that addresses the interaction of economics, ecology, and human/social well-being to achieve sustainable development. The commitment of HEIs to the principles of sustainable development and the adaptation of these to their unique contexts will help achieve the necessary institutional and systemic change in HEIs, making them models of sustainability in their own communities [6]. Several strategies are used by HEIs to teach sustainability, such as, among others, incorporating sustainability concepts into courses and research projects; developing specific curricula that incorporate sustainability as a central theme; problem-based learning to address real-world sustainability challenges; collaboration between universities, governments, and organizations to promote sustainable practices; interdisciplinary research and collaboration across disciplines to address sustainability challenges; engaging stakeholders, including consumers, in sustainability-related decision making; ecological literacy and the adoption of sustainable practices such as the creation of green campuses [6,20,22–25]. Within the framework of interdisciplinary and transdisciplinary analysis for sustainable development linking knowledge, innovation, society, and the environment, the model of the Quintuple Helix emerges [26], which incorporates the Triple Helix [27] and the Quadruple Helix [28]. This model focuses on the production and use of knowledge in the context of university–industry–government relations, integrates the media- and culture-based perspective of society by making citizens the main actors in decision making, and adds the environment; therefore, the Quintuple Helix can be construed as an approach that aligns with the principles of sustainable development and social ecology.

A representation of the Quintuple Helix model is shown in Figure 3.

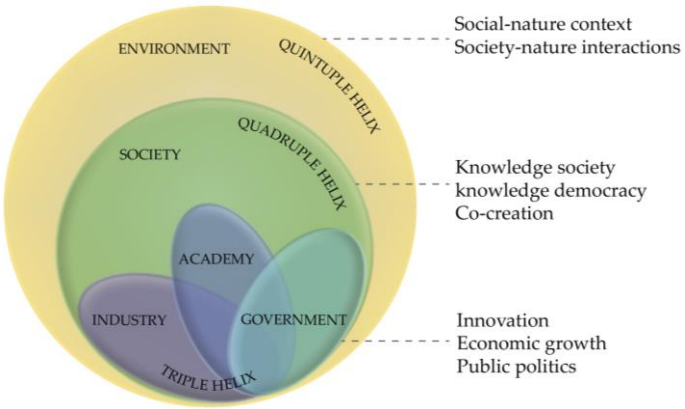

Figure 3. Adapted from Quintuple Helix model [29].

There is no single approach to teaching or learning sustainability; it depends on the ambiguous and changing nature of sustainability itself. True education for sustainability transcends the paradigm where sustainability is predetermined by experts and merely transmitted to students for reproduction. Instead, it necessitates a transformative shift in our pedagogical models, wherein educators are not just transmitters of knowledge

but active learners engaged in dynamic interactions. In this context, each participant contributes from their unique knowledge and perspective, fostering an environment open to normative, ethical, and spiritual discourse [30].

3.2. The Urban Living Labs—A Conceptual Understanding

Urban development constitutes one of the specialized domains within the purview of LLs. The concept of LLs has its beginnings in the 1960s and 1970s with the Scandinavian participatory design movement [31]. The LL approach represents a user-centered research methodology that creates open, interdisciplinary environments in multiple real-life contexts, where participants can question challenges and come up with joint solutions to innovate new services, products, and social infrastructures [32–43].

ULLs arise as a response to the challenge of balancing economic prosperity and social cohesion within cities while concurrently pursuing environmental sustainability [44]. Urban living labs emerge as a form of experimentation and collective urban governance that addresses the sustainability challenges and opportunities of cities [8–10]. They are urban sites created to design, test, and learn from real-time social and technical innovation in a given location where experimental interventions for sustainability transitions can provide a learning scenario in which joint participation between research organizations, public institutions, the private sector, and community actors is practiced to deliver innovative urban solutions [44–47]. ULLs can be expansively envisioned as innovation hubs, dedicated to the advancement of novel products, systems, services, and processes. They employ methodologies that involve individuals throughout the development lifecycle, engaging them as users and active participants to explore, scrutinize, experiment with, test, and assess innovative concepts, scenarios, systems, processes, and imaginative solutions within intricate real-world contexts [48]; their primary aim is to foster the co-creation and empowerment of various stakeholders during the experimental process, operating in a 'triple' or 'quadruple' helix mode that converges the realms of science, policy, business, and civil society [49,50]. While consensus remains elusive regarding the precise definition of a ULL [9,47,51], it can be said that ULLs are spaces for collaboration and experimentation to address complex urban problems with the participation of various local actors. The concept of a ULL 2.0 is also mentioned in the literature and refers to an evolution of ULLs, which seeks to enhance inclusivity, sustainability, and their transformative capacity [51]. Even though ULL projects and methodologies exhibit considerable diversity, the inherent advantages consistently revolve around user engagement and the utilization of outcomes for the creation of tailored products and services that are deployable within the everyday living environments of citizens [52]. Facilitation of citizen participation and collaboration, joint participation processes in the design of city solutions, and empowerment of citizens are the main benefits of seeing the city as a ULL [53].

3.2.1. Characteristics of ULLs

Chronéer identifies seven key components and four specific dimensions in ULLs [17]. These components encompass governance models that include the management structure, political frameworks, and policies; funding and business models; the tangible, real-life setting; a commitment to innovative experimentation; collaborative partnerships with end-users that are part of the quadruple helix; the approach to engaging different stakeholders and collecting data; and the ICT and infrastructure. The dimensions within which to consider ULLs are, firstly, as a persistent institution dedicated to advancing sustainability within an urban setting; secondly, as a methodology through which citizens and various stakeholders actively engage, employing diverse approaches to devise sustainable solutions; thirdly, as a localized endeavor context, where local issues can be addressed while making meaningful contributions to global challenges; and fourthly, as a political endeavor aimed at the implementation of sustainable practices. Steen and Bueren conducted an evaluation of ninety sustainable urban innovation projects and identified nine characteristics of ULLs in four dimensions: objectives, activities, participants, and context [54]. Voytenko

identified the main characteristics as rooted in a specific geographical context, emphasizing experimentation and continuous learning, active user participation and engagement, strong leadership and project proprietorship, and evaluation and improvement [9]. Reviewing more authors such as Costa, Federley, Schliwa, and Wallin, it was possible to identify fourteen characteristics of ULLs, framing them in the dimensions established by Steen and Bueren [42,47,55,56].

Table 1 shows the description of the characteristics of ULLs according to their dimensions.

Table 1. Characteristics of ULLs according to their dimensions.

Dimension	Features	Description
Objectives	Urban innovation	Goals focused on generating new knowledge and new products that provide solutions to new urban challenges.
	Formalized knowledge production	Learning and experimenting through the production and exchange of knowledge among participants, achieving replication of innovation in other places, in real life, or fostering future innovation.
	Increasing urban sustainability	Search for local solutions focused on promoting sustainable development.
Activities	Co-creation	Joint stakeholder participation in the development process, where the target users are involved and have decision-making power.
	Development of innovation	ULLs focused on developing a product or innovation.
	Experimentation and learning	Conducting experiments within a tangible environment, collaboratively generating knowledge and ideas alongside users.
	Interaction	Feedback, evaluation, and improvement.
Participants	Members of the quintuple helix	Users, public and private actors, and knowledge institutes actively contribute to the innovation and development process.
	Users	As the center of the planning process, they are involved in all states of ULLs.
	Decision-making power	All participants have decision-making power at different stages of the process.
Context	Real-life scenario	Their activities unfold within the practical context of real-world application, resulting in the creation of novel urban environments, practices, and patterns, among other outcomes.
	Geographical coverage	It can be situated in various settings, such as a region, agglomeration, city, district, neighborhood, road, corridor, or a building. Typically, its boundaries are clearly delineated and manageable in size; its growth projection ranges from the smallest unit (building) to the macro (city).
	Part of an ecosystem	It integrates seamlessly into the conventional planning system and practices, encompassing urban areas ranging from cities to smaller units.
	Time focus	It is developed through short- and long-term actions to achieve significant changes in the environment.

Source: adapted from [42,47,55,56].

3.2.2. Criteria for Differentiation of ULLs

Due to the experimental nature of ULLs, it is difficult to compare them; however, several ways of classifying them can be found in the literature. Marvin, Bulkeley, Mai, and McCormick based their classification on the form of inquiry of ULLs, and categorized them into three types: strategic, civic, and organic. They suggest considering this classification as ideal, as it does not fully represent reality, but captures the essence of the different ways of designing a ULL [44].

Table 2 shows the description of each category.

Table 2. Types of ULL according to the form of inquiry.

Category	Description
Strategic	They focus on planning and developing long-term urban strategies, creating and testing new technologies and solutions to urban problems. Key actors are local governments, urban planning organizations, businesses, universities, and research centers. They seek to involve the community in decision making and in the implementation of sustainable urban solutions.
Civic	They focus on addressing specific social and community problems, such as poverty, unemployment, and pollution. Key actors are civil society and non-profit groups such as NGOs and community-based and grassroots organizations. They seek to involve the community in identifying problems and implementing solutions.
Organic	They focus on the creation and improvement of urban infrastructure to improve the quality of life of residents. The key actors are residents and local community organizations. They seek to involve the community in identifying problems and implementing solutions at the local level.

Source: adapted from [51].

Voytenko sees four issues as relevant when comparing ULLs: how the approach is operationalized; the type of ULL partnership and the role of research institutions; the types of challenges addressed by different ULLs; and the role of sustainability, the environment, and the low-carbon agenda in ULLs [9].

Costa and Wallin, based on the type of approach and the solutions they propose to address urban challenges, classify ULLs into three types: technology-driven, transition-driven, and citizen-driven [42,47]. This type of classification does not preclude the possibility of overlap, given the diverse methods used to enhance participant engagement and to foster the creation innovative solutions.

Table 3 shows the description of the classification and the main results.

Table 3. Classification of ULLs according to how they are driven.

Category	Description	Results
Driven by technology	Aimed at developing and implementing radical technological innovations. They are based on a research environment that gathers information about the users of the artifact or service that has been used to improve the urban environment and/or local services.	Technological innovation
Driven by transition	An ecosystem facilitating the convergence of diverse stakeholders from science, policy, business, and civil society, in order to enact a local governance model. It extends to self-organized groups beyond formal urban planning, aiming to advance sustainability through innovative urban experiments in defined areas.	Sustainable development
Citizen-driven	These initiatives are based on a platform that places residents and their communities at the forefront, considering them users who actively seek solutions to their challenges. In this context, other stakeholders acknowledge ownership of the process.	Citizen empowerment

Source: adapted from [42,47].

Juujärvi and Pesso distinguish three types of ULLs: the first type utilizes the urban setting as a technology-enhanced research environment, facilitating the gathering of feedback from a broad citizenry via websites or sensor-based approaches. Their primary objective is the enhancement of the urban environment and the improvement of local services. In the second type, citizens are also involved in the creation by contributing to the design and development of local services and urban artifacts (e.g., communal playgrounds, childcare facilities, etc.). The third type of ULL involves the development of innovative urban planning methods and tools, engaging citizens in the process to facilitate the formulation of a shared vision for the area and to enhance planning procedures. This approach also fosters increased accessibility and mutual learning among stakeholders [57].

Scholl and Kemp classified ULLs according to five key characteristics. Firstly, they function as hybrid entities straddling the interface between local government and society.

Secondly, they serve as hubs for experimental learning, fostering innovative governance models. Thirdly, a hallmark is their role as multi-stakeholder settings, involving local government and prioritizing co-creation. Fourthly, they employ co-creation to conduct experiments. Lastly, they tackle intricate issues through a multidisciplinary approach, leveraging knowledge from various fields [58].

Table 4 presents a compilation of the different ULL classifications made by some authors.

Table 4. Classification of ULLs according to some authors.

Author	Approach	Category
Marvin [44]	Inquiry	Strategic.
		Civic.
		Organic.
Voytenko [9]	Objectives	How to operationalize the approach.
		The nature of partnership and the roles played by research institutions.
		The types of challenges they address.
		The role of sustainability, the environment, and the low-carbon agenda.
Wallin, Costa [34,47]	Impulse	Technology-driven.
		Driven by transition.
		Citizen-driven.
Juujärvi and Pesso [58]	---------	Technology-assisted research environment.
		Citizens participating in the creation.
		Development of new types of urban planning.
Scholl and Kemp [59]	Planning	Hybrid organizational forms on the borderline between local administration and society.
		Experiential learning places for new forms of governance.
		Multi-stakeholder environments focused on co-creation.
		They use co-creation to conduct experiments.
		They tackle complex problems in a multidisciplinary way.

Source: author.

3.3. Learning Environments through the ULL Approach

Although the purpose of this study is to explore the ULL approach and its learning environment within higher education, considering that LLs handle a concept similar to that of ULLs [17], this section also analyzes two interesting examples of LLs that have been presented as learning environments in HEIs.

Next, the analysis of six cases is presented: two LLs and four ULLs. The selection of these cases was based on their relevance to this research, and particularly the variety of approaches, results, and barriers as learning environments in HEIs to promote ESD. It is through hermeneutics and the exhaustive literature review mentioned in the methodology that the qualitative elements for this analysis are defined.

In this way, for the analysis of the cases, a table was designed that shows the type, approach, characteristics, results, limitations, and challenges of LLs and ULLs. Given that different ways of classifying ULLs were found in the literature and that some of them overlap, classification according to the form of research was considered for the analysis in this study, since it captures the essence of the different ways of designing a ULL. In the case of LLs, a classification according to type was not made; since it is not the subject of this study, a LL was used.

Despite these differences in classification, the six case studies presented in this study demonstrate how ULLs and LLs can function as efficient learning environments in HEIs to promote ESD.

3.3.1. LOW3, Universitat Politécnica de Catalunya (UPC)

The LL LOW3 is a research and educational project used as a tool for ESD and the promotion of sustainable solutions in architecture; it consists of a prototype solar house that functions as a platform for teaching, research, and innovation [59]. Table 5 describes the type, approach, characteristics, results, limitations, and challenges of the project.

Table 5. Type, approach, characteristics, results, limitations, and challenges of LOW 3.

Type	**Living lab**	
Approach	EDS through LL LOW3, which consists of a prototype solar house that functions as a platform for teaching, research, and innovation in the field of sustainability in architecture. The project is based on a participatory and multi-stakeholder approach, involving students, researchers, companies, research entities, and local administration in the search for sustainable solutions.	
Dimension	Features	
Objectives	Innovation	Develop innovative user-centered teaching formats. Promote education and research in sustainability. Serve as a platform for innovation in higher education.
	Formalized knowledge production	
	Increasing sustainability	
Activities	Co-creation	Regular courses, innovation seminars, educational visits, open days. "Live-at-LOW3" home occupation experiment. Collaboration between the academic and professional worlds of architecture. Liaison with the productive sector of the construction industry. Collaboration with the public administration.
	Innovation development	
	Experimentation and learning	
	Interaction	
Participants	Members of the quintuple helix	Master's and PhD students, teachers, research groups, professional associations, collaborating companies, municipalities.
	Users	
	Decision-making power	
Context	Real-life scenario	Innovation platform, solar house. ETSAV University Campus in Sant Cugat del Vallés, Barcelona. It was developed over a period of two years (2008–2010) and was subsequently reconstructed and renamed Living Lab LOW3 in 2011.
	Geographical coverage	
	Part of an ecosystem	
	Time focus	

Source: adapted from [54].

In this context, the outcomes underscore the emergence of a user community transcending conventional academic boundaries. A notable synergy among stakeholders has facilitated opportunities for pioneering sustainability-related innovations. Remarkably, students conveyed their contentment regarding their involvement, depicting it as an intensive and paradigm-shifting experience. However, substantial hindrances encompass administrative and legal intricacies, mandating unwavering dedication from all stakeholders. Further, fiscal requisites pose a critical challenge, as this project remains in perpetual evolution, underscoring a steadfast commitment to ongoing enhancement.

3.3.2. Living Lab in Building Engineering Education, Carleton University

The study deals with the use of a LL as an experiential learning tool in building engineering education. The project involved the use of a building equipped with state-of-the-art building control technologies, allowing students to have access to a living laboratory resource [60].

Table 6 describes the type, approach, features, outcomes, limitations, and challenges of the project.

Table 6. Type, focus, characteristics, results, limitations, and challenges of LLs.

Type	Living Lab.	
Approach	Experiential Learning Theory (ELT). It is a student-centric approach that provides fresh experiences coupled with guided reflection. This empowers students to steer their own learning journey prior to, during, and following the experience. The study uses this approach to design and evaluate a series of learning tasks that use real-life data from a living laboratory to enhance student learning in engineering.	
Dimension	Features	
Objectives	Innovation	Provide students with a practical and realistic experience in the study of building performance. Promote evidence-based decision making and engineering information literacy. Improve students' understanding of the real challenges faced by professionals in the field of building engineering.
	Formalized knowledge production	
	Increasing sustainability	
Activities	Co-creation	Collection of performance data from an occupied and operating building. Analysis of the data collected to assess the building's performance in terms of energy and indoor environmental quality. Development of solutions to improve building performance. Presentation of solutions and discussion of results.
	Innovation development	
	Experimentation and learning	
	Interaction	
Participants	Members of the quintuple helix	Students of building engineering. Course teacher. Technical and support staff responsible for data collection and building maintenance.
	Users	
	Decision-making power	
Context	Real-life scenario	The living lab is an occupied and functioning building that serves as a learning and research resource for building engineering students. The building has an integrated building automation system that enables the collection of real-time performance data. Building engineering course for fourth year and postgraduate students, duration 4 months.
	Geographical coverage	
	Part of an ecosystem	
	Time focus	

Source: adapted from [55].

The study revealed that students derived practical skills in building performance data collection and analysis, enhancing their engineering information literacy and evidence-based decision making. Furthermore, they achieved a profound comprehension of real-world challenges confronted by building engineering experts. Nonetheless, challenges included data complexity, particularly its volume, which overwhelmed some students. Some lacked fundamental skills, like Excel proficiency and unit conversion knowledge, making it challenging to bridge traditional and experiential learning. Occasionally, the quality of written work suffered due to Excel-based submissions without spell-checking. Future course revisions aim to enhance alignment and balance among course elements.

3.3.3. University Campus, University of Manchester

The University of Manchester established a living laboratory framework on its campus by transforming it from a passive to an active environment for teaching and learning [61].

Table 7 describes the type, approach, characteristics, outcomes, limitations, and challenges of the project.

This case shows several positive results such as the integration of the living lab approach into the university's sustainability policy, the creation of practical projects on campus, and a significant increase in website traffic in the first nine months. The projects covered various areas, fostering collaboration between different faculties. While the study did not directly assess student learning, it did highlight strong student interest in living lab projects. Challenges included competition for academic time, required initial investment, and unfamiliarity with the approach. To address global sustainability challenges, expanding the living laboratory model was identified as a necessary step.

Table 7. Type, approach, characteristics, results, limitations, and challenges of the ULL University of Manchester.

ULL University of Manchester		
Type of ULL	It could be considered a strategic ULL, due to its focus on innovation and experimentation in an urban environment, engaging sectors and disciplines to address specific challenges on the university campus and in the city of Manchester; also involving non-academic stakeholders such as Siemens, the City Council, and Transport Greater Manchester to achieve sustainable solutions.	
Approach	Transform the University of Manchester campus into a site for teaching and applied research on sustainability.	
Dimension	Features	
Objectives	Urban innovation	Coordinate projects horizontally and vertically to maximize the benefit of the knowledge produced to non-academic stakeholders.
	Formalized knowledge production	Incorporate the living lab methodology into the university's sustainability framework and produce a series of practical projects on campus.
	Increasing urban sustainability	Facilitate and simplify the identification of applied projects by partnering students with non-academic stakeholders.
		Create a community of interest and show how living labs enhance collaboration across sectors and disciplines.
Activities	Co-creation	Publish living lab project opportunities online and the results of previous projects.
	Innovation development	Conduct video interviews with non-academic stakeholders to explain specific challenges.
	Experimentation and learning	Provide easy access to existing data, such as energy use in buildings.
	Interaction	Work with non-academic stakeholders to address specific problems or infrastructures.
		Undertake deliberate experiments leading to societal or material changes.
		Integrate clear aspects of continuous and refinement.
Participants	Members of the quintuple helix	University students.
	Users	Non-academic stakeholders, such as Siemens, the City Council, and Transport for Greater Manchester.
	Decision-making power	University environmental consultants.
Context	Real-life Scenario	Urban Living Lab at the University of Manchester focused on sustainability and collaboration across sectors and disciplines.
	Geographical coverage	
	Part of an ecosystem	
	Time focus	

Source: adapted from [56].

3.3.4. University Campus, Massachusetts Institute of Technology (MIT)

The study focuses on leveraging the campus as an active learning environment and crafting innovation instruments like Process Wheels, Learning Adventure Card, and Discover Living Lab Web App. These tools draw upon the conceptual frameworks of Urban Living Lab (UL3) to encourage profound learning experiences and novel perspectives, by intertwining insights from various disciplines including cognitive science, fine arts, developmental psychology, philosophy, organizational behavior, applied mathematics, and popular culture [62].

Table 8 describes the type, approach, characteristics, results, limitations, and challenges of the project.

Among the positive outcomes of the case study, interactivity and play are shown to be effective tools for collaborative learning and knowledge transfer in living lab (LL) research. Interdisciplinary collaboration and the reduction of social distance between team members are essential for the success of the LL. Understanding user goals is necessary for improved learning and the understanding of concepts. Challenges include comparing the variety of LL research results and their subjective evaluations. Its major limitations

are the costs of developing innovation tools and acquiring funding. LL management is complex and involves multiple stakeholders and diverse timelines. Documenting and sharing LL research stories, especially older work, is problematic. There is a need to scale up LL research results for greater accessibility.

Table 8. Type, approach, characteristics, results, limitations, and challenges of the ULL MIT.

ULL MIT		
Type of ULL	It could be inferred that it is a strategic ULL that focuses on innovation and interdisciplinary collaboration to solve complex problems, because specific tools are developed with multi-stakeholder collaboration to create sustainable solutions.	
Approach	Use of LL and development of user participation innovation tools based on ULL's learning frameworks to maximize meaningful interactions.	
Dimension	Features	
Objectives	Urban innovation	Promote profound learning and fresh perspectives by interconnecting insights from diverse domains including cognitive science, fine arts, developmental psychology, philosophy, organizational behavior, applied mathematics (game theory), and popular culture. Encourage interdisciplinary collaboration. Facilitate research on campus by making it more accessible. Provide organizational tools that connect people, ideas, and processes.
	Formalized knowledge production	
	Increasing urban sustainability	
Activities	Co-creation	Development of innovation tools such as Process Wheels, Learning Adventure Cards, and the Discover Living Lab Web App. LAB-O-RAMA events. Surveys and polls to assess the effectiveness of tools and awareness of research in living labs.
	Innovation development	
	Experimentation and learning	
	Interaction	
Participants	Members of the quintuple helix	Students, researchers, teachers, administrative staff. MIT external partners.
	Users	
	Decision-making power	
Context	Real-life scenario	Massachusetts Institute of Technology (MIT).
	Geographical coverage	
	Part of an ecosystem	
	Time focus	

Source: adapted from [63].

3.3.5. Water Resources Plan for the Itapocu River Basin (PRHCRI), University of Southern Santa Catarina (Unisul)

This study deals with the role of HEIs in promoting sustainable development in communities. It presents the case of Unisul and its participation in the Water Resources Plan of the Itapocu River Basin, which involved the community, the government, and HEIs in the creation of a participatory management system to preserve and use natural resources in an efficient way [22].

Table 9 describes the type, approach, characteristics, results, constraints, and challenges of the project.

This case study accentuates favorable outcomes, notably the tangible sustainability enhancements in the Itapocu river basin community. Emphasis is placed on the pivotal role of environmental education and community involvement in shaping public policy. Higher education institutions (HEIs) are lauded as agents of transformative social and environmental change, primarily through the adoption of sustainable practices. The effectiveness of environmental education and knowledge dissemination is underscored, facilitated by comprehensive training initiatives, research endeavors, and collaborative ventures involv-

ing the university, the government, and the community. While this case underscores HEIs' potential to drive global sustainability endeavors, it also illuminates potential obstacles, including financial constraints, lukewarm engagement from key stakeholders, community awareness deficits, coordination complexities, and project intricacies.

Table 9. Type, focus, characteristics, outcomes, limitations, and challenges of the ULL PRHCRI.

UNISIL Itapocu River Basin Project		
Type of ULL	It has more characteristics of a civic approach, as it focuses on the collaboration between the university, government, and community to promote sustainability in the Itapocu river basin.	
Approach	It focuses on how the university (Unisul), in collaboration with the government and the community, has managed to improve sustainability in the Itapocu river basin through sustainable initiatives and environmental education.	
Dimension	Features	
Objectives	Urban innovation	Improve sustainability in the Itapocu river basin community. Bring together the actors responsible for the management of sanitation systems, the government, private sector institutions, and environmental organizations. Promote environmental education and its link with the main economic activities. Develop public policies focused on water use and treatment.
	Formalized knowledge production	
	Increasing urban sustainability	
Activities	Co-creation.	Environmental education programs in community schools and train educators, researchers and stakeholders. Develop public policies based on data collection on water quality, water resources use, and water treatment. Create supporting actions to help define the priority of each policy. Provide reports on the results of meetings and interactions with the basin.
	Innovation development	
	Experimentation and learning	
	Interaction	
Participants	Members of the quintuple helix	Actors responsible for the management of sanitation systems. The government, encompassing the State Governor, their team, the Secretary of State for Economic and Sustainable Development, the Director of Water Resources, and the Water Resources Planning Manager. Corporate entities within the private sector, such as local industries and businesses. Environmental advocacy groups. Local community. University.
	Users	
	Decision-making power	
Context	Real-life scenario	Itapocu river basin in Brazil. Water resources project of the Itapocu river basin.
	Geographical coverage	
	Part of an ecosystem	
	Time focus	

Source: adapted from [13].

3.3.6. Malmo Innovation Platform (MIP), University of Lund

This study deals with the Malmo Innovation Platform (MIP), a ULL that provides a variety of real-time learning environments in a local context by combining physical and virtual spaces; it also brings together municipal, business, academic, and community actors in joint innovation in the renovation of apartment buildings in southeast Malmo [45].

Table 10 describes the type, approach, characteristics, results, and the limitations and challenges of the project.

Table 10. Type, approach, characteristics, results, and limitations and challenges of the ULL MIP.

Malmo Innovation Platform (MIP)		
Type of ULL	It could be classified as a strategic ULL, as it focuses on the Malmo Innovation Platform (MIP) and how it is used to catalyze learning in urban sustainability through collaborative educational activities.	
Approach	To provide students with real-time learning experiences and diverse learning environments in a local context, where they use the Malmo Innovation Platform (MIP) to catalyze learning in urban sustainability.	
Dimension	Features	
Objectives	Urban innovation	Develop skills and competencies needed to be agents of change in urban sustainability. Provide a safe and supportive learning environment for students to feel comfortable expressing themselves, interacting, asking questions, and reflecting.
	Formalized knowledge production	Integrate academic, business, and civic forces to jointly build an active knowledge base and analyze and question values and patterns of behavior to find alternative forms of systemic change.
	Increasing urban sustainability	To provide students with real-time learning experiences and diverse learning environments in a local context so that they experience that moving toward urban sustainability is an iterative process and that there are no simple solutions.
Activities	Co-creation	Participation in workshops, role-plays, research and evaluations of IPM activities. Debate and discussion on energy efficiency and renovation targets in the building sector. Collaborative education activities as part of the Industrial Environmental Economics course. Reflection seminars.
	Innovation development	
	Experimentation and learning	
	Interaction	
Participants	Members of the quintuple helix	Master's students. Teachers and other learning professionals. IPM stakeholders, including industry partners.
	Users	
	Decision-making power	
Context	Real-life scenario	Sustainability programs at Lund University. Urban sustainability projects in the IPM. Physical and virtual learning environments.
	Geographical coverage	
	Part of an ecosystem	
	Time focus	

Source: adapted from [39].

This case, in terms of its positive results, facilitated the development of basic skills and competencies to promote urban sustainability. In addition, it established a safe and supportive learning environment that encouraged student interaction, expression, questioning, and reflection. The different interested parties such as academic, business, and civic entities fostered the collaborative creation of knowledge and the critical analysis of values and behaviors, seeking alternatives for systemic change. Diverse real-time learning experiences in local contexts underscored the iterative nature of urban sustainability progress. Positive course evaluations revealed students' appreciation for hands-on integration. However, the most relevant challenges included student participation in research projects, which required support from researchers, and barriers such as insufficient support for building renovations and organizational complexities in southeast Malmö.

4. Discussion

ULLs are established as enabling spaces in which members of the academic community have the opportunity to participate in concrete projects and collaborate with different actors

outside their field, innovating and co-creating solutions, with the intention of addressing sustainability-related issues in real environments. Considering this statement, the ULL approach, as a strategy for teaching and learning is of great importance in the argument of sustainability challenges, as it offers a practical and applied environment in which to address these challenges in the real urban context.

The collaborative exercise applied from ULLs contributes to the development of awareness and commitment to sustainability, in addition to fostering interdisciplinarity, a basic feature to address sustainability challenges comprehensively and effectively. In short, working as a team not only generates awareness about sustainability but also gets different actors to work together, the latter being very important because different perspectives are needed to solve sustainability challenges.

In all the case studies presented, ULLs show a number of characteristics and dimensions that make them particularly useful in addressing ESD challenges.

Cases such as LOW3 (UPC) and MIT's ULL focus on integrating sustainability into higher education through research and education; however, they differ in their approach. The former focuses on promoting sustainable solutions in architecture, while the latter focuses on innovation and interdisciplinary collaboration to solve problems of greater complexity.

The case of the University of the South of Santa Catarina (Unisul) seeks to highlight the HEI as the institution in charge of promoting SD in communities, differentiating itself from the first two cases that emphasize the participation of the community and the government in the creation of a participatory management system to preserve and use natural resources efficiently.

The last three cases function efficiently as learning environments, addressing sustainability challenges and opportunities in higher education. Although they differ from the other case studies in their approach and application, they share common objectives for the promotion of ESD based on experimentation and application of teaching and learning tools.

Among the advantages, the ULL provides a practical and applied learning environment for students, i.e., a framework for experimentation, which allows them to apply knowledge to real situations in real time and to develop practical and problem-solving skills; it encourages students' active participation in identifying and solving sustainability problems in their local community, which can help develop their awareness and commitment to sustainability; it fosters interdisciplinary collaboration between students and academics from different disciplines, which can help address sustainability problems in a more holistic and effective way.

However, the ULL also presents disadvantages and challenges. Implementing a ULL requires significant upfront investment, which can be an obstacle for some institutions. Competition for academics' time could also present a problem, as participation in a ULL may require a significant commitment of time and resources. The management of ULLs is complex due to the involvement of multiple stakeholders, and a lack of commitment from any of the key players could jeopardize the success of the project. It may also be difficult to scale the model to address sustainability challenges globally, which may limit its usefulness in some contexts. In addition, the difficulty of comparing research results in ULLs due to the variety of possible outcomes and the subjectivity in evaluating them is an issue.

It is important to emphasize that, according to the literature reviewed, it can be evidenced that ULLs are aligned with the Sustainable Development Goals (SDGs) established by the United Nations. In this sense, ULLs can play an essential role in achieving several of these SDGs, including, but not limited to, SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 17 (Partnerships to Achieve the Goals).

Overall, ULLs can be an effective teaching and learning strategy in HEIs toward ESD. However, it is important to keep in mind its limitations and challenges when considering its implementation; steps should be taken to address these challenges and ensure that a ULL is effective and sustainable in the long term.

No specific empirical results were found in the evaluation of ULLs as teaching and learning tools toward ESD in HEIs. In this study, for the analysis of the case studies, a table was developed describing the type, approach, characteristics, results, and limitations and challenges of various ULLs in relation to ESD. The classification was made according to the form of inquiry; and the characteristics were framed in the dimensions of objectives, activities, participants, and context. This table could be considered a starting point for the creation of a tool to evaluate the relationship and/or impact of ULLs with ESD in HEIs, as it provides information on the type of ULL, its approach, characteristics, and results in relation to sustainability.

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