frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 31 May 2024
DOI 10.3389/feduc.2024.1412380

OPEN ACCESS

EDITED BY
Frank Eckardt,
Bauhaus-Universität Weimar, Germany

REVIEWED BY
Jesús M. Siqueiros,
National Autonomous University of Mexico, Mexico
Carmelina Cosmi,
National Research Council (CNR), Italy

*CORRESPONDENCE
Ivetheyamel Morales
ivetheyamel.moralesv@ug.edu.ec

RECEIVED 04 April 2024
ACCEPTED 14 May 2024
PUBLISHED 31 May 2024

CITATION
Morales I, Segalás J and Masseck T (2024) Evaluation of the urban living lab in HEIs towards education for sustainable development (E-ULL-HEIs).
Front. Educ. 9:1412380.
doi: 10.3389/feduc.2024.1412380

Evaluation of the urban living lab in HEIs towards education for sustainable development (E-ULL-HEIs)

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

[1]School of Architecture and Urbanism, University of Guayaquil, Guayaquil, Ecuador, [2]Doctoral Programme in Sustainability, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, [3]Research Institute for Sustainability Science and Technology, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, [4]Department of Architectural Technology, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain

This study explores the implementation of Urban Living Labs (ULLs) in Higher Education Institutions (HEIs) to promote Education for Sustainable Development (ESD). It adopts a methodology that integrates a mixed approach, combining literature review, validation with experts in the field and analysis of case studies. A structured evaluation tool is proposed based on three constructs: Synergy, Strategy and Pedagogy, which cover the essential characteristics of the three thematic axes: ULLs, ESD and HEIs, through seven indicators. This tool is applied to examine the effective-ness of ULLs in promoting sustainable practices within the university context. The results, vali-dated through experts, exploratory factor analysis and Cronbach's alpha coefficient, demonstrate the reliability and consistency of the evaluative indicators, highlighting the crucial role of ULLs in the integration of sustainability in the curriculum, experiential learning, and the impact social and community. This approach allowed the identification of successful practices and common challenges in the implementation of ULL, as well as the development of a framework of indicators adapted to the specific needs of HEIs. The study concludes by emphasizing the transformative potential of ULLs in HEIs to advance towards sustainable urban transitions, underscoring the need for robust evaluative tools to optimize the contribution of higher education to global sustainable development.

KEYWORDS

Education for Sustainable Development (ESD), Higher Education Institutions (HEIs), Urban Living Labs (ULL), assessment tool, urban innovation, interdisciplinarity, curriculum integration, experiential learning

1 Introduction

In a constantly evolving world, humanity faces contemporary challenges such as economic, social and environmental sustainability. This underlines the pressing need for governments, private enterprise and professionals to attain new knowledge and skills towards sustainability. In this context, education becomes an essential tool to achieve the comprehensive sustainable development of society, so much so that UNESCO recognizes education as one of the Sustainable Development Goals (SDGs), focusing on ensuring inclusive and quality education (SDG 4). Specifically, target 4.4 emphasizes the importance

of equipping students with skills for sustainable development. ESD is defined as an educational approach that seeks to integrate sustainable development principles, values and practices into all aspects of education and learning. This approach aims to empower students to actively contribute to a more sustainable, equitable and just world by promoting a shift in awareness and action towards sustainability (Organización de las Naciones Unidas para la Educación [UNESCO], 2017; Rieckmann, 2017).

HEIs play a crucial role in promoting sustainability, not only because of their ability to influence future leaders and professionals, but also because of their role as models of sustainable practices within their own communities (Cortese and Hattan, 2010; Purcell et al., 2019; Hernández-Diaz et al., 2021). HEIs become centers of knowledge creation and transfer to society through research and teaching (Segalàs, 2019). The transition towards sustainability in HEIs is complex, requiring profound reorganization and redefinition in order to be effective in their role as agents of change (Tilbury, 2011; Lozano et al., 2013; Rotondo et al., 2023). HEIs should focus on principles of responsibility and sustainability, seeing themselves as laboratories in which students learn to critically examine social conditions, develop ideas for a better future and implement sustainable solutions (Bauer et al., 2021). This involves not only integrating sustainability into the curriculum, but also into research, campus operations and community outreach (Leal Filho et al., 2019; Mori et al., 2019; Skanavis et al., 2020).

Adopting a holistic and collaborative approach is fundamental to the successful implementation of ESD. This means addressing sustainability through an interdisciplinary and transdisciplinary perspective that engages multiple stakeholders and disciplines, recognizing the interconnectedness between economics, ecology and human/social well-being (Wals, 2014; Withycombe Keeler et al., 2016; Masseck, 2017; Greve et al., 2020; Finnveden et al., 2022). Reframing knowledge in multiple contexts and dimensions requires innovative teaching and learning strategies (Bindal, 2022). The Quintuple Helix model is an example of how HEIs can foster effective collaboration between academia, industry, government, society and the environment, thus promoting innovation and knowledge for sustainable development (Carayannis and Campbell, 2021, 2010).

Furthermore, ESD in HEIs must transcend the traditional paradigm of knowledge transmission, promoting a pedagogical shift towards more interactive learning, where educators and students are co-learners in a process of joint exploration (Sterling and Orr, 2001; Sinakou et al., 2022). This involves creating spaces for critical dialogue and reflection on values, ethics and social responsibility, essential elements for fostering sustainable awareness and action. By embracing ESD, HEIs not only prepare students to face the challenges of the future, but also position themselves as leaders in the transformation towards a more sustainable society (Moreno et al., 2015; Henríquez Guajardo, 2018).

In this context Urban Living Labs (ULLs) represent an innovative paradigm in urban research and development, serving as experimental platforms to design, test and learn about sustainable urban solutions in real-life contexts (Bylund et al., 2022). These living labs are defined by their participatory approach, where actors from diverse sectors collaborate to co-create innovations that address complex urban challenges, embedding sustainability into the fabric of everyday life (Bulkeley et al., 2016). By situating experimentation in real urban environments, ULLs provide fertile ground for applied research, collaborative learning and citizen engagement in sustainable innovation processes (Sengers et al., 2019; Korzer et al., 2020; Von Wirth et al., 2020; Rizzo et al., 2021; Scholl and de Kraker, 2021; Paço and Azeiteiro, 2022). These living laboratories have become catalysts for sustainable change, facing real dilemmas in delineated geographical settings (Marvin et al., 2018; Schäpke et al., 2018; Von Wirth et al., 2019).

The incorporation of ULLs in HEIs presents a unique opportunity to move towards ESD. ULLs can serve as experiential teaching-learning strategies, providing students and academics with a real laboratory in which to apply sustainability theories, evaluate innovative solutions and reflect on their socio-ecological impact (Evans et al., 2016; Verhoef et al., 2020). This practical and contextualized approach fosters the development of key competences for sustainable development, such as critical thinking, complex problem solving and interdisciplinary collaboration skills (O'Brien et al., 2021).

Furthermore, ULLs facilitate a deeper connection between HEIs and their communities, aligning education and research with local needs and challenges. By engaging students, academics, industry, government and citizens in the co-design of sustainable solutions, ULLs promote meaningful learning that transcends the boundaries of the classroom, encouraging social responsibility and civic engagement (McCormick and Hartmann, 2017; Amorim et al., 2020). This multidimensional collaboration not only enriches the educational experience, but also contributes to the creation of innovative and contextualized solutions, increasing the relevance and impact of ESD.

The implementation of ULLs as a teaching-learning strategy in HEIs towards ESD requires an integrated institutional approach that promotes interdisciplinarity, collaboration and project-based learning. The creation of physical and virtual spaces dedicated to sustainable experimentation enables students and academic staff to actively participate in applied research and the development of sustainable solutions, preparing them to face the challenges of sustainable development in their future professional careers and personal lives (Wolff, 2020).

However, despite their rising importance and potential impact on promoting ESD, a gap has been revealed in the scientific literature. Surprisingly, there is a lack of attention to the systematic and effective evaluation of ULL as a strategy for ESD in HEIs (Morales et al., 2023). Studies of Living Labs (LL) such as LOW3 (Masseck, 2017) at the Polytechnic University of Catalonia (UPC), a prototype solar house that functions as a platform for teaching, research and innovation, or Carleton University's case of a building as LL (O'Brien et al., 2021), describe experiences and findings, but do not present a project evaluation methodology with respect to ESD. The same is true for ULLs at the University of Manchester (Evans et al., 2015), Massachusetts Institute of Technology (MIT) (Wolff, 2020), University of Southern Santa Catarina (Amorim et al., 2020). This gap translates into an opportunity to improve our understanding of how ULLs can be designed and operated as effective tools for promoting sustainability.

Several studies, such as (Voytenko et al., 2016), underline the need to develop standardized tools to compare urban laboratories in different contexts, facilitating shared learning among ULLs

(Steen and Bueren, 2017) emphasize the importance of common methodologies to maintain consistency in the assessment of these labs. (Bulkeley et al., 2016) highlight how a unified methodological framework can significantly improve efficiency in the implementation and assessment of these labs. According to (Baccarne et al., 2014), a standardized methodology gives transparency and credibility to ULLs, while (Marvin et al., 2018) emphasizes the importance of a common framework to ensure the strategic relevance of ULLs in the context of sustainable cities. This underlines the fundamental importance of having a standardized methodology for assessing ULLs as tools for ESD in HEIs, as it allows for effective comparison of ULLs in different contexts and geographies, facilitating analysis and identification of successful practices that can be replicated. It also provides a common framework for assessing all ULLs in a consistent way, resulting in reliable data and objective assessments, which are essential for measuring progress, identifying weaknesses and improving strategies. It also promotes the sharing of findings and results among HEIs and other stakeholders, fostering collective learning and contributing to continuous improvement. Finally, it facilitates the implementation of ULLs, saving time and resources, allowing HEIs to focus on the impact they want to achieve, and providing transparency and credibility to ULLs, which increases their strategic relevance and contributes significantly to HEIs' sustainability goals.

This lack of attention to the systematic and effective evaluation of ULL as a strategy for ESD in HEIs translates into an opportunity to improve our understanding of how ULLs can be designed and operated as effective tools to promote sustainability. This research therefore focuses on addressing this gap by developing a specific assessment tool to reveal and measure the role of ULLs in promoting ESD in HEIs. Measuring and understanding the role of ULLs in transforming our societies towards a more sustainable future is of paramount importance, and this tool aims to provide a solid basis for its evaluation and continuous improvement.

This background underlines the main objective of this study: to develop and validate an evaluation tool to measure the impact of ULLs in promoting ESD in HEIs. This research seeks to achieve the following specific objectives:

- Identify key dimensions for evaluating ULL projects in the context of ESD in HEIs.
- To develop an evaluation methodology through indicators for each identified dimension.
- Validate the evaluation tool.
- Apply the evaluation tool to different ULL projects.

The research questions to be answered are the following:

- What are the key dimensions for evaluating ULL projects in the context of ESD in HEIs?
- How can these dimensions be measured through specific indicators?
- Is the resulting evaluation tool relevant, clear and applicable according to experts in the field?
- Are its indicators valid and reliable?
- Can the tool be used for different types of ULL projects?

2 Materials and methods

The tool was developed in four phases: first, the identification of dimensions and the development of indicators, second, validation by experts, third, validation by statistical methods, and fourth, representation and interpretation of the results.

- Phase 1: Identification of dimensions and approach to indicators

In this phase, through an exhaustive literature review using the SALSA (Search, Appraisal, Synthesis and Analysis) methodology (Grant and Booth, 2009), the key dimensions to be considered in the evaluation of ULL concerning ESD in HEIs were identified. The approach was based on the main characteristics of the three thematic axes ULL, ESD and HEIs and their relationship to each other. For each dimension an indicator was developed including description, assessment method and interpretation of results. **Supplementary Appendix 1** shows an outline of the literature review based on the SALSA methodology.

- Phase 2: Validation through experts

The dimensions and indicators from phase 1 were analyzed with a panel of seven experts for validation. The panel consisted of professionals with expertise in the areas of education and sustainable development, research methodology, ULL and academics from HEIs. These experts assessed each of the dimensions and indicators in terms of relevance, clarity and applicability using a three-point Likert scale. In the case of the indicators that were not scored with the maximum value, the reasons for this were discussed. The expert validation format is shown in **Supplementary Appendix 2**. Adjustments were made according to the comments and suggestions of the experts, and the dimensions and indicators were changed or refined. The process of exchanging information with the experts was carried out via email and video calls. All stages of the process were socialized with the experts in order to receive the respective feedback.

- Phase 3: Validation through statistical methods

Using the SALSA methodology (Grant and Booth, 2009), a representative sample of ULL projects involving HEIs was selected. Projects of various geographical regions and sizes was included, ensuring a variety reflecting different contexts and approaches of ULLs. Data were collected through the projects' records on their websites and published scientific articles. This information was used to assess each of the indicators validated in Phase 2.

To confirm the structural validity of the dimensions and indicators, Exploratory Factor Analysis (EFA), (Mavrou, 2015) was used, considering factor loadings greater than 0.722 for sample sizes $n = 50$ as significant. This analysis helped to confirm whether the proposed dimensions were adequately reflected in the indicators. To assess the reliability of the indicators, Cronbach's alpha coefficient was calculated (Avecillas and Lozano, 2016). A value above 0.7 is considered indicative of high internal consistency. All analyses were conducted using the freely licensed software R, (Kronthaler and Zöllner, 2021). Correlations between indicators

were examined to validate their relevance and effectiveness in measuring aspects of ESD in ULLs. The results allowed us to adjust or reaffirm the validity of the proposed indicators. In those cases, where the results indicated the need for revision, adjustments were made by redefining or eliminating them to ensure that they accurately reflect the interaction between ULLs and ESD in HEIs.

- Phase 4: Interpretation and representation of results

Considering the criteria of uniformity and reduction of bias, it was assumed that all validated indicators are of equal importance for the promotion of ESD in HEIs, therefore the sum of the indicators was taken as the total project rating. If there are n projects in a ULL, the average of the n projects corresponds to their total rating. In a scale of interpretation of the results, the aim was to explain the situation of the ULL project about the ESD in a simple way, for which the Likert methodology was used (Matas, 2018).

For the representation, data visualization tools were used to create graphical representations of the results. This included graphs and diagrams that helped to interpret the data in an intuitive and accessible way.

3 Results

3.1 ULL, ESD and HEI characteristics

The literature review reveals the main characteristics of the three thematic axes, which are widely accepted and promoted by relevant experts and organizations in the field of study. This section introduces the key findings derived from the review.

- Characteristics of ULLs

Chronéer et al. (2018) highlights seven components and four fundamental dimensions for understanding ULLs, such as the governance models, funding strategies, commitment to innovation experimentation, the tangible and real environment, the collaborative partnerships with end-users that form part of the quadruple helix; the approach to engaging different stakeholders and collecting data; and the key technological infrastructure for their operation. This analysis is enriched by the work of Steen and Bueren, who, after studying ninety projects, identify nine essential characteristics of ULLs in four dimensions: objectives, activities, participants and context (Steen and Bueren, 2017) and by Voytenko et al. (2016), who highlights experimentation, continuous learning and active user participation as pillars (Voytenko et al., 2016). Costa, Federley, Schliwa, and Wallin extend this perspective, identifying fourteen characteristics that reflect the adaptability of ULLs to diverse geographical contexts and challenges (Schliwa, 2013; Federley et al., 2014; Wallin, 2014; Costa, 2017).

- Characteristics of ESD

UNESCO highlights ESD as a crucial pillar for achieving a more sustainable future, underlines the key characteristics of ESD by emphasizing the empowerment of learners through the acquisition of knowledge, skills, values and attitudes that promote meaningful changes towards sustainability (Juujärvi and Pesso, 2013; Organización de las Naciones Unidas para la Educación [UNESCO], 2017; Leicht et al., 2018; Van Balen, 2021).

- Characteristics of HEIs towards SD

UNESCO highlights education as crucial to achieving sustainable development, promoting the need for educational systems that define relevant learning objectives, introduce empowering pedagogies and adopt sustainability principles in their management (Organización de las Naciones Unidas para la Educación [UNESCO], 2017; Leicht et al., 2018; Van Balen, 2021).

Table 1 shows a summary of the characteristics of ULLs, ESD, HEIs according to the ULL dimensions.

3.2 Dimensions

The selection and validation of the dimensions was based on in-depth knowledge derived from a comprehensive literature review, initially identifying ten dimensions. Following the analysis and recommendations of the expert panel, these were condensed into seven. These seven crucial dimensions cover the key aspects of the three thematic axes, ensuring the coherence of the tool within the context of ESD in HEIs. **Table 2** presents the dimensions to be assessed in the ULL and their relation to ESD and HEIs.

3.3 Indicators

Figure 1 presents the final results of the average of the expert assessments of the indicators in terms of relevance, clarity and applicability. These results reflect a synthesis of expert perspectives, providing a comprehensive assessment of each indicator within the study.

Tables 3–9 detail the development of the indicators validated by the experts for the proposed dimensions. Each table includes the description of the indicator and its corresponding evaluation method. A three-point Likert scale is used to assess the evaluation criteria, with the options 0: Low, 1: Moderate and 2: High. The formula for calculating each indicator is the weighted average of the criteria scores, defined as:

$$INDICATOR = (\Sigma(Ci * PCi))/N$$

Where:

Σ represents the sum of the criteria assessed in the projects.

Ci represents the score assigned to criterion i on a scale from 0 to 2.

PCi represents the importance or relevance of the criterion in the set of criteria. All criteria are considered to be of equal importance.

N is the total number of criteria assessed.

(1) Objectives and scope

This dimension assesses the clarity and alignment of project objectives with ESD principles and goals through the indicator clarity of objectives (COI). The assessment criteria and interpretation of the indicators are described in **Table 3**.

(2) Participants and actors involved

10.3389/feduc.2024.1412380

TABLE 1 Characteristics of ULLs, EDS, HEIs according to their dimensions.

Dimension	ULL	ESD	HEIs
Objectives	Urban innovation, formalized knowledge production, increased urban sustainability. (Steen and Bueren, 2017).	Promotion of critical thinking, critical analysis and evaluation, evidence-based solutions, focus on a sustainable future. (Sterling and Thomas, 2006; Tilbury, 2011; Van Wijk, 2013; Wals, 2014).	Curricular integration, clear policies and strategies, responsibility and transparency, promotion of diversity and equity. (Tilbury, 2011; Wals, 2014).
Activities	Related to co-creation, innovation, experimentation, learning and interaction. (Juujärvi and Pesso, 2013; Schliwa, 2013; Wallin, 2014).	Inclusive education, practical learning, projects, practical activities and real-world experiences, evaluation and monitoring. (Sterling and Thomas, 2006).	Continuing education, sustainable management, community engagement, experiential education, sustainable research, promoting diversity and equity. (Tilbury, 2011; Barth and Michelsen, 2013; Lozano et al., 2013; Rieckmann, 2017)
Participants	Members of the quintuple helix, users at the centre of the planning process, all with decision-making power. (Schliwa, 2013; Federley et al., 2014; Steen and Bueren, 2017).	It includes all age and demographic groups, from formal education in schools to non-formal education in the community. (Sterling and Thomas, 2006; Wals, 2014; Leal Filho, 2018).	Community engagement, collaboration with other institutions and organizations. (Tilbury, 2011; Wals, 2014).
Context	It is developed in real scenarios, with short and long-term actions, projecting from the minimum unit to the macro level. (Juujärvi and Pesso, 2013; Schliwa, 2013; Voytenko et al., 2016).	Adaptation to local contexts: Recognizes that challenges and solutions vary according to geographical and cultural location, and adapts to local realities. (Sterling and Thomas, 2006; Wals, 2014; Leal Filho, 2018).	
Inter-disciplinary approach	Based on the integration of various academic disciplines and knowledge to address complex problems in a comprehensive manner. (Chronéer et al., 2018).	Integration of disciplines: Incorporates diverse academic disciplines and expertise to address complex problems holistically. (Sterling and Thomas, 2006; Wals, 2014; Leal Filho, 2018).	Sustainable research: HEIs should encourage multidisciplinary research focused on critical areas. (Wals, 2014).

TABLE 2 Dimensions to be assessed in ULL and their relation to ESD and HEIs.

Dimension	Relation	
Objectives and scope	ESD	ULL's goals are aligned with the principles of ESD, such as promoting environmental, social and economic sustainability.
	HEIs	HEIs define institutional objectives that reflect their commitment to ESD, and these in turn are reflected in the ULL objectives.
Participants and actors involved	ESD	The involvement of students, faculty, community and other stakeholders is consistent with the inclusive and participatory approach to ESD.
	HEIs	HEIs foster collaboration with different stakeholders to broaden their impact in promoting sustainability and ESD.
Interdisciplinarity	ESD	Projects address sustainable issues and foster interdisciplinarity, aligned with ESD principles.
	HEIs	HEIs promote the inclusion of ESD-related projects in their curricula and academic programs.
Curricular integration	ESD	The integration of ULL projects and activities into the academic curriculum is aligned with ESD, facilitating students' training in sustainability.
	HEIs	HEIs are proactive in incorporating sustainable approaches into their academic programs and curricula.
Experiential learning and research	ESD	Experiential learning is linked to ESD, enabling students to apply knowledge in real-life scenarios and develop practical skills by addressing sustainable challenges.
	HEIs	As part of their commitment to ESD, HEIs actively promote experiential learning and student participation in sustainable projects.
Community impact	ESD	A key goal of ESD is to have a positive impact on the community by improving the quality of life of communities and promoting sustainability.
	HEIs	HEIs value and encourage their students and faculty to engage in projects that have a positive impact on the community and promote sustainability.
Resources and sustainability	ESD	Allocation of resources and promotion of sustainable practices are essential for the long-term implementation of ESD programs and projects.
	HEIs	HEIs allocate resources and plan for the long-term sustainability of their ESD-related initiatives and commitments.

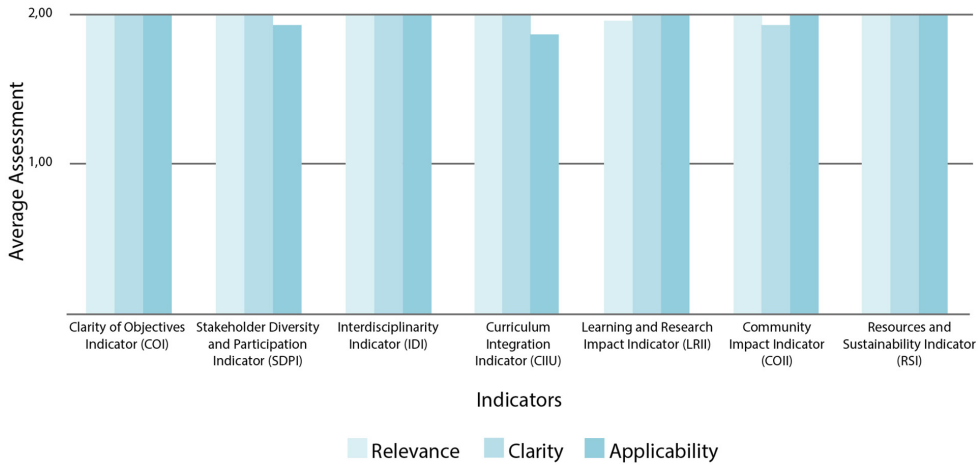

FIGURE 1
Relevance, clarity and applicability of the indicators.

TABLE 3 Clarity of Objectives Indicator (COI).

Criteria (C)	Description	Assessment	
Clarity of Objectives	Project objectives are clearly defined and expressed in an understandable way.	0 Low	Objectives unclear and ambiguous.
		1 Moderate	Objectives moderately clear, but with some ambiguities.
		2 High	Objectives completely clear and unambiguous.
Alignment with ESD	Project objectives are aligned with ESD principles and goals, promote environmental, social and economic sustainability.	0 Low	Objectives not aligned, do not promote sustainability.
		1 Moderate	Objectives partially aligned, promote up to two ESD principles.
		2 High	Objectives fully aligned, fully promote environmental, social, and economic sustainability.

Data Collection: The assessment is conducted through documentary review, including the mission, policies, and strategic plans of the project. Interpretation: A COI close to 2 indicates that the project objectives are clear, specific, and aligned with ESD principles. A value close to 0 suggests a lack of clarity or alignment with sustainability objectives.

This dimension assesses the measures both the diversity and the degree of participation of key stakeholders in the project. The assessment criteria and interpretation of the indicators are described in Table 4.

(3) Interdisciplinarity

This dimension assesses the extent to which the project promotes and fosters interdisciplinarity by involving various academic disciplines in its sustainability-related projects and activities. The assessment criteria and interpretation of the indicator are described in Table 5.

(4) Curricular Integration

This dimension assesses the extent to which the project is integrated into the curriculum and academic programs of HEIs to promote ESD. The assessment criteria and interpretation of the indicator are described in Table 6.

(5) Experiential learning and research

This dimension evaluates the impact of project activities on student learning and academic research related to sustainable development. The assessment criteria and interpretation of the indicators are described in Table 7.

(6) Community impact

This dimension evaluates the impact of project activities on the local community and their contribution to community well-being. The assessment criteria and interpretation of the indicators are described in Table 8.

(7) Resources and sustainability: assessment criteria and interpretation

This dimension evaluates resource management and the promotion of sustainable practices in the project, considering economic, environmental and social aspects. The assessment criteria and interpretation of the indicators are described in Table 9.

3.4 Validation by statistical methods

3.4.1 Sample

In the statistical analysis, fifty projects were selected, all involving the university and prioritizing the diversity of approaches and contexts. Table 10 details relevant information on ULLs from

TABLE 4 Stakeholder Diversity and Participation Indicator (SDPI).

Criteria (C)	Description	Assessment	
Stakeholder diversity	Mapping and categorization of actors in the quintuple helix.	0 Low	Lack of diversity, limited and homogeneous actors.
		1 Moderate	Some diversity of actors (two or three actors of the quintuple helix).
		2 High	Maximum diversity, a wide range of actors of different categories (more than three actors of the quintuple helix).
Degree of Involvement	Power in decision-making.	0 Low	Minimal involvement (Only one actor has decision-making power).
		1 Moderate	A higher degree of involvement is evident (two or three actors with decision-making power).
		2 High	Active participation (more than three actors with decision-making power).

Data Collection: Documentary review (identification of actors and degree of participation). Interpretation: A score close to 2 suggests that the project has achieved an inclusive and collaborative environment, with various stakeholders united in sustainability projects, increasing the chances of success in promoting ESD. A value close to zero indicates limited participation or insufficient stakeholder diversity.

TABLE 5 Interdisciplinarity Indicator (IDI).

Criteria (C)	Description	Assessment	
Diversity of disciplines per project	Identification of the academic disciplines represented in the project.	0 Low	No diversity of disciplines: Unidisciplinary projects.
		1 Moderate	Low diversity of disciplines (two disciplines).
		2 High	High participation of disciplines (more than two disciplines).

Data Collection: Documentary review (academic affiliation of participants and diversity of subject areas represented). Interpretation: A score close to 2 reflects a strong interdisciplinarity in the project, with a diversity of disciplines, while a score close to zero suggests a lack of interdisciplinarity.

TABLE 6 Curriculum Integration Indicator (CIIU).

Criteria (C)	Description	Assessment	
Level of Curricular Integration	Number of courses that are incorporated into the project.	0 Low	Indicates that the project is not integrated into the HEI curriculum. No courses or programs address activities related to the project.
		1 Moderate	There is moderate integration of project activities into the HEI curriculum. At least one course or program addresses project activities.
		2 High	Indicates that project activities are actively and significantly integrated into the HEI curriculum. Two academic courses or programs integrate the activities.

Data Collection: Documentary review of academic courses and programs that are directly related to the ULL project. Interpretation: A value close to 2 denotes full curricular integration of project activities in academic courses, while a result close to zero indicates low curricular integration, suggesting that project activities have a limited impact on teaching and learning in HEIs.

which the fifty projects were drawn, thus providing a basis for understanding the nature of the chosen sample.

3.4.2 Results of the integrated project evaluation

Table 11 presents the overall results of the evaluation of the fifty projects, which were extracted from the ULLs detailed in Table 10.

3.4.3 Exploratory Factor Analysis (EFA)

The results of the EFA are presented in Table 12.

In all cases the factor loadings are significant, values greater than 0.722 for sample sizes n = 50. The SDPI, IDI, and COII indicators have high factor loadings on the ML1 factor, suggesting that they represent a common construct. The indicators COI and RSI have high factor loadings on the ML2 factor, indicating that they are closely related and represent another distinct construct. The indicators CIIU and LRII have high factor loadings on ML3, suggesting that these indicators represent a third construct. The proportion of variance explained by each factor (ML1, ML2, and ML3) is 30.4, 23.9 and 23.3%, respectively, for a cumulative total of 77.6%. This indicates that the three factors together explain a good part of the variability in the data. Parallel analysis suggests that the number of factors to retain is 3.

3.4.4 Cronbach's alpha coefficient

Table 13 presents the results of the reliability analysis using Cronbach's alpha coefficient for each of the factors resulting from the EFA.

In all cases the value of Cronbach's alpha coefficient (raw alpha) is greater than 0.7. This indicates an excellent internal consistency between the indicators of each factor, which means that the two indicators are measuring coherent and related aspects within the model. The value of the signal-to-noise ratio for each factor (ML1, ML2, ML3) is 6.9, 8.9 and 6.9 respectively, indicating strong signal (consistency) compared

TABLE 7 Learning and Research Impact Indicator (LRII).

Criteria (C)	Description	Assessment	
Skills Development	Assesses whether students have developed skills related to sustainability: research, problem solving, teamwork and communication.	0 Low	Students have experienced limited development of sustainability-related skills (one skill).
		1 Moderate	Shows that students have developed sustainability-related skills to some extent, but not fully, (two skills).
		2 High	Indicates that students have experienced significant development of sustainability-related skills (more than two skills).
Publications and Presentations	Assesses whether the research results have been published in academic journals, presented at conferences or other academic forums.	0 Low	Research results have not been published in academic journals or presented at conferences or other academic forums.
		1 Moderate	Research results have been published in a limited number of academic journals or conferences, but not extensively (up to two publications, conferences or forums).
		2 High	Suggests that the research results have been widely disseminated in academic journals or presented at some academic conferences or forums, (three publications or more).

Data Collection: Documentary review / surveys / interviews. Analysis of academic results related to student learning and research conducted in the project. Interpretation: An LRII close to 2 reflects a significant impact of the ULL project on student skills development and knowledge generation, while a value close to zero suggests a limited effect of the project in these areas.

TABLE 8 Community Impact Indicator (COII).

Criteria (C)	Description	Assessment	
Improved Quality of Life	Assesses whether the project activities contribute to a better quality of life in the community, considering the aspects of health, education, employment and access to services.	0 Low	The activities have not had a significant impact on the quality of life of the community. No improvements are observed in any of the aspects.
		1 Moderate	The project actions have contributed to some extent to a better quality of life in the community. There are improvements in one of the aspects.
		2 High	Indicates that the project activities have had a significant and positive impact on the quality of life in the community. There are noticeable improvements in more than one of the aspects.
Reduction of Environmental Impacts	Evaluates whether the project's actions have had a positive impact on reducing negative environmental impacts on the community, such as pollution abatement or sustainable management of natural resources.	0 Low	No efforts to reduce pollution or sustainably manage natural resources are observed.
		1 Moderate	Actions have contributed to some extent to the reduction of negative environmental impacts in the community. There may be limited efforts to reduce pollution or promote sustainable management of natural resources (reduction of one impact is evident).
		2 High	Indicates that the activities have had a significant and positive impact on reducing negative environmental impacts on the community. Notable efforts to reduce pollution and promote sustainable management of natural resources are observed (two or more impacts are reduced).

Data Collection: Documentary review, surveys of residents, interviews with community leaders, analysis of socio-economic data, and direct observation of changes in the community. Interpretation: An COII close to 2 indicates a significant effect of the project on improving quality of life, reducing environmental impacts and fostering community participation, while an COII close to zero suggests a limited impact on these aspects.

TABLE 9 Resources and Sustainability Indicator (RSI).

Criteria (C)	Description	Assessment	
Efficiency in the Use of Resources	Assesses the efficiency in the use of financial resources in the project. It considers the planning and execution of the budget, and the results, objectives and benefits achieved with the level of resources used.	0 Low	Indicates that the project has not demonstrated significant efficiency in the use of resources. The results and benefits achieved do not justify the level of resources used.
		1 Moderate	Shows that the project has achieved some efficiency in the use of resources, but there may be room for further improvement in resource management efficiency.
		2 High	Indicates that the Laboratory has demonstrated high efficiency in the use of financial resources. Resources are managed efficiently and effectively to achieve the project objectives.
Promotion of Sustainable Practices	Evaluates whether the laboratory promotes sustainable practices in its internal operations and projects, including the promotion of sustainability in the community. The following are considered sustainable practices: waste management, energy efficiency, renewable energy, sustainable transport, water conservation, sustainable construction and design, sustainable agriculture, environmental education and awareness, community involvement, sustainable innovation.	0 Low	Indicates that the promotion of sustainable practices in the project is minimal (one sustainable practice).
		1 Moderate	Indicates that the project has promoted at least two sustainable practices.
		2 High	Indicates that the project has effectively promoted more than two sustainable practices.

Data Collection: Documentary review of information related to resource management and sustainability at ULL. This includes financial data, environmental management practices, sustainable procurement policies and social responsibility practices. Interpretation: An RSI close to 2 indicates efficient resource management and a strong project approach to sustainability, while a value close to zero implies inefficient resource management and a weak focus on sustainability.

to noise (inconsistency), which further supports the reliability of the indicators.

3.4.5 Grouping indicators into constructs

Based on the results of the EFA and Cronbach's alpha coefficient, the distribution of indicators is made under three identifiable constructs in the analysis: Synergy, Strategy and Pedagogy. The following describes each of them.

- Synergy: It covers how interaction and cooperation between different sectors (SDPI) and disciplines (IDI) can have an effective impact on the community (COII), achieving results that go beyond what each could achieve individually.
- Strategy: It encompasses both clarity and precision in defining objectives (crucial aspect of COI) and the ability to achieve sustainable and far-reaching results (core of RSI).
- Pedagogy: Covers both the integration of new knowledge and approaches into the curriculum (CIIU) and the impact on learning and research (LRII).

These constructs are fundamental to understanding how interaction and cooperation between different sectors and disciplines can effectively impact the community, the importance of having clear and precise objectives to achieve sustainable and long-range results, and how the integration of new knowledge and approaches in the curriculum affects learning and research.

3.4.6 Interpretation and representation

The overall evaluation of the project is obtained through the sum of the seven indicators; therefore, the maximum possible evaluation is 14 points. The mechanism for interpreting the results corresponds to a four-point Likert scale. It should be stressed that an accurate interpretation will depend on the specific results of each indicator, thus allowing for a more comprehensive analysis of the strengths and weaknesses of the project.

(0–5): In this range, the project shows very low performance on most or all of the indicators assessed.

(5–8): In this range, the project demonstrates low to moderate performance on most indicators. Although there may be areas for improvement, some dimensions of the project may be performing acceptably.

(8–11): In this range, the project shows moderate to high performance on most indicators. This suggests that the project is achieving satisfactory results in most of the areas assessed.

(11–14): In this range, the project demonstrates high performance on all or most indicators. This indicates that the project is performing excellently in promoting sustainability in HEIs.

The graphical representation in the form of a stacked bar chart allows visualizing the results of the individual indicators and the total project rating, which facilitates comparison between projects. An example is presented in **Figure 2A**.

The representation of the indicators through a radial diagram makes it easier to visualize the strengths and weaknesses of the

TABLE 10 Revised ULLs basic database.

No.	Project	City/Country	University	Approach	References
1	UNALAB	Eindhoven, The Netherlands, Tampere, Finland, Genoa, Italy	PolyU, Luleå University of Technology, TU/e, University of Stuttgart, University of Aveiro	Explores solutions to existing challenges: segregation, unemployment, education.	(UNALAB, 2017)
2	MK SMART	Milton Keynes, United Kingdom	The Open University	Explores innovative solutions in the areas of transport, energy and water management.	(Cook and Valdez, 2021; MK:Smart, 2024)
3	AMS	Marineterrein, Amsterdam	WUR, TU Delft, MIT	Design solutions to urban challenges generating positive social impact on the road to better cities.	(AMS Institute, 2023)
4	University of Manchester	Manchester, United Kingdom	University of Manchester	Transform the University of Manchester campus into a centre for teaching and applied research in sustainability.	(Evans et al., 2015; Voytenko et al., 2016; Leal Filho and Dahms, 2018)
5	The Green Village	Berlageveld, The Netherlands	Tu Delft	Explore solutions to existing challenges, responding from academia.	(Van Wijk, 2013; Koppers, 2015; Van Geenhuizen, 2019)
6	Cuenca del Río Itapocu	Santa Catarina, Brazil	Unisul	Improve sustainability in the Itapocu river basin through sustainable initiatives and environmental education.	(Amorim et al., 2020)
7	TEC de Monterrey	Monterrey, Nuevo León, Mexico	Monterrey Tech	Transform cities, prioritizing urban sustainability, social innovation and participatory governance, encompassing consultancy, academia, research and dissemination.	(Huertas et al., 2021; C+Lab, 2023; DistritoTec, 2023)
8	Urban Lab Guadalajara	Guadalajara, Mexico	Jesuit University of Guadalajara, ITESO	Understand urban performance metrics through evidence-based decision tools, seeking more equitable, safe and resilient communities, and fostering responsible urbanization and technological innovation.	(ITESO and Universidad Jesuita de Guadalajara, 2023)
9	Centro de Desarrollo Urbano Sustentable (CEDEUS)	Santiago, Chile	Pontifical Catholic University of Chile University of Concepción	Develop sustainable and equitable improvements in people's quality of life, recognizing social demands and promoting balanced urban development.	(CEDEUS, 2023)
10	InnovaLab	Santiago, Chile	Saint Tomas	It fosters social innovation, seeking creative solutions to community problems, through collaborative spaces that empower those affected and students for projects with social impact.	(Santo Tomás Universidad, 2023)
11	UrbanLab, Bogotá Región	Bogotá, Colombia	University of Bogota Jorge Tadeo Lozano	Urban development, public policy and innovation.	(Jorge, 2023)
12	Laboratorio para Otros Urbanismos	São Paulo, Brazil	University of São Paulo	Investigate and critically map urban and housing policies in São Paulo and other Brazilian metropolitan areas.	(Sao Paulo Universidad, 2023)
13	Ciudad Universitaria Inteligente (CIU)	Mexico City, Mexico	UNAM, National Autonomous University of Mexico	Smart city solutions and urban governance.	(Pérez, 2013)
14	Delta	Guayaquil, Ecuador	University of Guayaquil	Mobility solutions.	(Hugo et al., 2018)

project. Up to two projects can be represented unambiguously. **Figure 2B** shows an example of a representation of indicators.

4 Discussion

In the field of ESD in HEIs, ULLs present themselves as innovative tools that seek to effectively integrate sustainability principles into university education. Several ULL projects in university contexts have demonstrated their potential to foster pedagogical innovation, active student participation and interdisciplinary collaboration. Despite their growing adoption, the scientific literature reveals a significant gap: the lack of a standardized methodology to assess the impact and effectiveness of ULLs as strategic tools in the educational context (Morales et al., 2023). Several studies such as (Voytenko et al., 2016; Steen and Bueren, 2017; Marvin et al., 2018) and others highlight the importance of developing standardized methodologies to

TABLE 11 Overall project evaluation results (Ev.Rs.).

N°	Ev.Rs.	N°	Ev.Rs.	N°	Ev.Rs.	N°	Ev.Rs.	N°	Ev.Rs.
P1	9.00	P11	10.50	P21	9.00	P31	10.00	P41	9.00
P2	11.00	P12	11.50	P22	10.50	P32	9.50	P42	9.00
P3	11.00	P13	10.00	P23	8.50	P33	8.50	P43	8.50
P4	9.50	P14	8.50	P24	10.50	P34	8.00	P44	11.00
P5	11.00	P15	7.50	P25	7.50	P35	8.50	P45	6.50
P6	10.00	P16	10.50	P26	10.50	P36	9.00	P46	9.00
P7	10.50	P17	10.00	P27	8.00	P37	7.00	P47	10.50
P8	10.50	P18	7.50	P28	9.00	P38	7.50	P48	10.00
P9	8.50	P19	11.00	P29	10.00	P39	9.50	P49	11.50
P10	8.00	P20	8.50	P30	8.50	P40	9.00	P50	14.00

TABLE 12 EFA Results.

Factors	Indicators							Ratio variation	Cumulative variation
	SDPI	IDI	COII	COI	RSI	CIIU	LRII		
ML1	0.789	0.799	0.922					0.304	0.304
ML2				0.995	0.812			0.239	0.543
ML3						0.776	0.996	0.233	0.776

Parallel analysis suggests that number of factors = 3.

TABLE 13 Cronbach's Alpha analysis results.

	ML1 (SDPI, IDI, COII)	ML2 (COI, RSI)	ML3 (CIIU, LRII)
Raw alpha	0.87	0.90	0.87
signal-noise	6.9	8.9	6.9

evaluate and compare ULLs, which would improve their efficiency, credibility and strategic relevance, fostering shared learning and their impact on sustainable development.

LL and ULLs exhibit a rich methodological diversity. Projects such as LOW3 at the Universitat Politècnica de Catalunya (Masseck, 2017), focused on the co-creation of sustainable solutions in architecture, and the Malmö Innovation Platform (MIP) at Lund University (McCormick and Kiss, 2015), which offers both virtual and physical participatory learning environments in building renovation, demonstrate this varied approach. Carleton University (O'Brien et al., 2021) uses Experiential Learning Theory for teaching in building engineering, while ULL at the University of Manchester (Evans et al., 2015) and MIT (Wolff, 2020) are notable for transforming the academic environment into a dynamic space for hands-on learning in sustainability. However, they reflect a plethora of approaches and objectives that, while valuable, make benchmarking difficult. The lack of unified criteria limits the ability of HEIs to measure ULL's impact on ESD. Although a general evaluation framework is proposed based on key aspects such as impact on teaching and sustainable learning, its practical application is challenging due to the uniqueness of each project.

The current status of ULLs in ESD shows great potential, but a standardized evaluation methodology is needed to accommodate the diversity of contexts and approaches, providing clear and consistent criteria for measuring their impact on ESD. This will enable HEIs to demonstrate the value of ULLs and harness their potential, effectively integrating sustainability into higher education.

This study addresses this gap by proposing a structured assessment tool to understand and quantify the role of ULLs in promoting ESD in HEIs. The standardized methodology aims to ensure consistency, comparability, shared learning and efficiency, providing a structured framework to facilitate implementation and evaluation, bringing transparency and credibility to the results obtained. This tool is not proposed as the only solution for developing ULLs, but as a framework to expand knowledge and guide the development of ULLs towards ESD in HEIs.

The design of the tool started from the theoretical analysis of the close relationship between the characteristics of ULLs, ESD and HEIs to identify the relevant dimensions towards sustainability. Initially, the literature review identified ten relevant dimensions which, through analysis and input from a panel of experts, were synthesized into seven. Subsequently, the results of the Exploratory Factor Analysis (EFA) suggested a more refined grouping of these indicators into three constructs: Synergy, Strategy and Pedagogy. This process of conceptual clarification and refinement is essential to ensure that the study accurately addresses the most influential and manageable elements in promoting ESD through ULLs.

This reorganization of the indicators into the three constructs reflects a more integrated and holistic view of ESD promotion in HEIs. It recognizes that: Clear and well-defined goals are the basis for long-term sustainable practices (Strategy). Participation and collaboration among various disciplines and actors, including the targeted community, are crucial for the successful and sustainable implementation of ESD initiatives (Synergy).

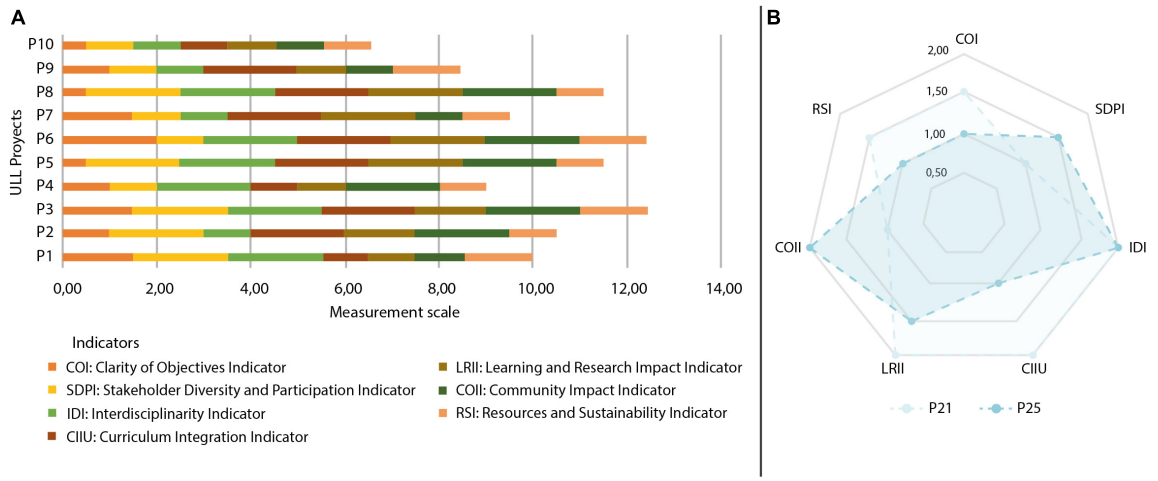

FIGURE 2
Example of graphical representation of **(A)** Integrated project evaluation (P); **(B)** Indicators of two projects.

Curricular integration and impact on learning and research are key elements of ULL effectiveness in academia (Pedagogy).

Each of the seven proposed dimensions has significant implications for sustainable development in HEIs, focusing on key aspects such as the alignment of objectives with ESD principles and the inclusion of diverse actors to address asymmetries of power and knowledge in sustainability projects. The integration of perspectives, knowledge and methodologies is essential for a holistic approach, while curriculum integration and experiential learning foster real-world problem solving, applied research and critical skills development, as well as understanding of sustainability challenges. In addition, strengthening the decision-making power of communities and ensuring that initiatives do not reproduce existing inequalities, along with assessing resource management and promoting sustainable practices, are essential.

The methodology is validated through reliability analysis, showing internal consistency in all indicators used. Although it involves a certain degree of subjectivity, the process of involving ESD and ULL experts, together with the use of robust statistical methods, ensures the relevance and pertinence of the assessment framework.

The evaluation of various types of projects in different contexts has validated the applicability of the tool, demonstrating the flexibility of the model. However, it faces practical challenges in terms of applicability and usefulness, as its effectiveness depends on access to accurate information and user training in ESD. In addition, the implementation of the model requires considerable time and analytical resources from institutions. Although it is designed to benefit ULL project leaders in their quest for continuous improvement, its ultimate usefulness lies with the entire educational community.

The tool provides a uniform framework for measuring the impact of ULLs, facilitating meaningful comparisons between labs with different approaches and context. This framework allows comparison of their impact in key areas, such as curriculum integration, resource use and community impact, among others. Some of the observations found in the evaluations are described below.

1. Objectives and Scope: Most ULL projects have clear objectives that address urban challenges related to sustainability. Milton Keynes, for example, focuses on smart solutions, while the Campus City Project focuses on mobility and energy.
2. Participants and Stakeholders Involvement: Each case involves stakeholders such as students, academics, businesses, local governments and citizens. Multi-stakeholder collaboration is a constant, as in the Delta Project in Guayaquil and CLEVER Cities in Milan, although managing differences remains a challenge (Hugo et al., 2018; Mahmoud and Morello, 2021).
3. Interdisciplinarity: All ULLs stress the importance of interdisciplinarity. The Green Village and the Campus City Project emphasize interdisciplinary collaboration to solve complex problems, combining knowledge from different areas.
4. Curricular Integration: Some ULLs, such as the one at the University of Manchester, integrate practical activities into the curriculum. Others, such as the Unisul project, do not yet take full advantage of this opportunity.
5. Experiential Learning and Research: Experiential learning is key in all ULLs, providing practical opportunities for students through real projects, encouraging creativity.
6. Community Impact: All ULLs seek to improve community conditions, from infrastructure to sustainable mobility, as evidenced by the Delta Project and CLEVER Cities.
7. Resources and Sustainability: Efficient use of resources and sustainability is a consistent theme in all ULLs reviewed, including long-term financing challenges.

4.1 Good practices

1. Collaboration and Participation: All ULLs assessed demonstrate the importance of multi-stakeholder collaboration. Projects such as CLEVER Cities in Milan and the Delta Project in Guayaquil made significant progress in involving local governments, students, businesses and the

wider community, which proved essential to gain support, generate ideas and ensure project success.
2. Interdisciplinary approach: The most successful ULLs, such as The Green Village and the Campus City Project, demonstrate that interdisciplinarity is key to developing comprehensive solutions. Combining knowledge from architecture, engineering, social sciences and other fields allows for a better understanding of urban problems and a more holistic approach to solving them.
3. Experiential Learning: The Campus City Project and the University of Manchester emphasize the value of hands-on learning in real projects. Students benefit from being directly involved in projects that address real urban problems, gaining essential skills for their future careers.

4.2 Impact

1. Community: ULLs positively impact communities by improving urban infrastructure and fostering social inclusion. The Delta Project in Guayaquil, for example, improved the quality of life by renovating public spaces and promoting sustainable mobility.
2. Innovation: ULLs also drive innovation in urban solutions. The City Project and The Green Village have created platforms where new technologies can be tested and refined for large-scale adoption (Van Wijk, 2013; Huertas et al., 2021).
3. Education: The involvement of students and academics in real ULL projects provides a valuable educational environment. Students apply theory in a practical context, strengthening their understanding of sustainability challenges.

4.3 Challenges

1. Long-term funding: Securing financial resources to sustain ULLs is a common challenge. Projects need to look for innovative funding models that will enable them to sustain themselves in the long term.
2. Multi-Stakeholder Management: Engaging and aligning diverse stakeholders with sometimes conflicting objectives requires advanced management skills. ULLs must establish clear governance structures to successfully navigate this challenge.
3. Institutional Constraints: Overcoming institutional barriers to integrating innovative approaches remains a challenge. It is essential to work towards institutions adopting more flexible frameworks that support innovation.

Academics also benefited from the practical, hands-on approach to cognitive teaching.

Although the ULLs cases coincide in their approach to urban sustainability and innovation, they differ in scope and context. By building on these differences, lessons can be learned from the experiences of others. Standardized assessment of ULLs allows for the identification of patterns and learning from shared experiences, facilitating the exchange of best practices and the identification of areas for improvement. Through a consistent methodology, ULLs can further improve their impact on community and sustainability education.

This tool has the potential to reveal critical aspects of ULL implementation and performance in various contexts. However, as sustainability is a constantly evolving field, new dimensions may emerge that require periodic revisions of the tool to maintain its relevance and effectiveness.

5 Conclusion

The study addresses a gap in the scientific literature on the systematic evaluation of ULLs as tools to promote ESD in HEIs. It provides a structured evaluative tool to understand and quantify the role of ULLs in this context, emphasizing their relevance given the growing importance of sustainability.

The research successfully validated seven key dimensions and their respective indicators for assessing ULL in the framework of ESD in HEIs. These dimensions cover crucial aspects such as objectives and scope, stakeholder participation, interdisciplinarity, curricular integration, experiential learning and research, community impact, and resources and sustainability.

Through Exploratory Factor Analysis (EFA) and Cronbach's alpha coefficient test, the study demonstrated a refined grouping of indicators into three constructs (Synergy, Strategy and Pedagogy) and confirmed a high reliability and internal consistency of the indicators.

The proposed methodology, which includes literature reviews, expert validation and statistical methods, provides a robust and structured guide for the assessment of ULLs. Despite some practical challenges, the model demonstrates flexibility and potential to adapt to various project contexts.

The evaluation results highlight the great potential of ULLs to drive innovation and sustainability in HEIs. However, their success depends on effective management of multi-stakeholder collaboration, integration into curricula and adequate assessment of community impact. Challenges include overcoming institutional barriers, securing sustainable funding and effectively managing power differentials between stakeholders.

Overall, this study provides a significant advance in the understanding and evaluation of ULLs in the framework of ESD in HEIs, offering a solid foundation for future research and practice in this evolving field.

The proposed model offers significant opportunities for further expansion. Its validation and application in a diverse range of educational, cultural and business settings in different geographical regions would not only deepen the understanding of ULLs in promoting ESD, but could also highlight the need to adapt and refine the model, thus enhancing its relevance and applicability in a global context.

Ultimately, such an expanded approach would allow for a more inclusive and representative assessment of ULLs, paving the way for a more meaningful impact on educational sustainability globally.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

IM: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Validation, Visualization, Writing—original draft, Writing—review and editing. JS: Supervision, Writing—review and editing. TM: Supervision, Writing—review and editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of the article. This research was financed by the Universidad de Guayaquil, through the UG 2016 scholarship program.

Acknowledgments

This research has been carried out with the support of the University of Guayaquil through its 2016 scholarship program and the Academic Vice Rectorate that approved the Delta Project, FCI project (Internal Competitive Funds).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1412380/full#supplementary-material

References

Amorim, W. S., da Silva Neiva, S., Castro, B. C. G., Deggau, A. B., Jonck, A. V., de Albuquerque, C. L., et al. (2020). "Higher education institutions as drivers of sustainable communities: A case study of the university of Southern Santa Catarina empowering the community," in *Proceedings of the universities and sustainable communities: Meeting the goals of the Agenda 2030, 805–23*, (Cham: Springer).

AMS Institute (2023). *Urban living labs proporciona un entorno co-innovador, en el que múltiples partes interesadas prueban, desarrollan y crean conjuntamente soluciones metropolitanas*. Amsterdam: AMS Institute.

Avecillas, D. X. A., and Lozano, C. P. P. (2016). Medición de la confiabilidad del aprendizaje del programa RStudio mediante alfa de cronbach. *Rev. Polit.* 37:68.

Baccarne, B., Schuurman, D., Mechant, P., and De Marez, L. (2014). "The role of urban living labs in a smart city," in *Proceedings of the The XXV ISPIM conference – innovation for sustainable economy & society*, (Dublin), 1–14.

Barth, M., and Michelsen, G. (2013). Learning for change: An educational contribution to sustainability science. *Sustain. Sci.* 8, 103–119.

Bauer, M., Rieckmann, M., Niedlich, S., and Bormann, I. (2021). Sustainability governance at higher education institutions: Equipped to transform? *Front. Sustain.* 2:2019–2022. doi: 10.3389/frsus.2021.640458

Bindal, N. (2022). Experiential learning in design education: Teaching construction and technology through active experimentation in interior and architectural design. *Int. J. Des. Educ.* 16:91.

Bulkeley, H., Coenen, L., Frantzeskaki, N., Hartmann, C., Kronsell, A., Mai, L., et al. (2016). Urban living labs: Governing urban sustainability transitions. *Curr. Opin. Environ. Sustain.* 22, 13–17. doi: 10.1016/j.cosust.2017.02.003

Bylund, J., Riegler, J., and Wrangsten, C. (2022). Anticipating experimentation as the 'the new normal' through urban living labs 2.0: Lessons learnt by JPI Urban Europe. *Urban Transf.* 4:456. doi: 10.1186/s42854-022-00037-5

C+Lab (2023). *Instituto tecnológico y de estudios superiores de Monterrey*. Available online at: https://c-lab.com.mx/ (accessed May 14, 2022).

Carayannis, E. G., and Campbell, D. F. J. (2010). Triple helix, quadruple helix and quintuple helix and how do knowledge, innovation and the environment relate to each other? *Int. J. Soc. Ecol. Sustain. Dev.* 1, 41–69. doi: 10.4018/jsesd.2010010105

Carayannis, E. G., and Campbell, D. F. J. (2021). Democracy of climate and climate for democracy: The evolution of quadruple and quintuple helix innovation systems introduction: Helices development in comparison. *J. Knowledge Econ.* 5, 2050–2082. doi: 10.1007/s13132-021-00778-x

CEDEUS (2023). *Centro de desarrollo urbano sustentable*. Available online at: https://www.cedeus.cl/ (accessed May 23, 2022).

Chronéer, D., Ståhlbröst, A., and Habibipour, A. (2018). "Towards a unified definition of urban living labs," in *Proceedings of the the ISPIM Innovation conference–innovation, the name of the game, Stockholm, Sweden on 17-20 June 2018*, (Tallinn: International Society for Professional Innovation Management (ISPIM)), 1–13.

Cook, M., and Valdez, A.-M. (2021). Exploring smart city atmospheres: The case of Milton Keynes. *Geoforum* 127, 180–188. doi: 10.1016/j.geoforum.2021.10.015

Cortese, A. D., and Hattan, A. S. (2010). Education for sustainability as the mission of higher education. *Sustainability* 3:9802. doi: 10.1089/SUS.2009.9802

Costa, M. (2017). *Classifying urban living labs: innovative approaches to address urban challenges*, Ph.D thesis. University of Rotterdam, Rotterdam.

DistritoTec (2023). *Instituto tecnológico y de estudios superiores de Monterrey, México. 2023*. Available online at: https://distritotec.tec.mx/es (accessed May 01, 2022).

Evans, J., Jones, R., Karvonen, A., Millard, L., and Wendler, J. (2015). Living labs and co-production: University campuses as platforms for sustainability science. *Curr. Opin. Environ. Sustain.* 16, 1–6. doi: 10.1016/j.cosust.2015.06.005

Evans, J., Karvonen, A., and Raven, R. (2016). *The experimental city: New modes and prospects of urban transformation of urban transformation*. Milton Park: Routledge, 1–12.

Federley, M., Friedrich, P., and Karlsson, A. (2014). *SubUrbanLab: D 2.1 Boundary conditions for successful urban living labs*. Available online at: https://cris.vtt.fi/ws/portalfiles/portal/33322603/SubUrbanLab_D2.1_Boundary_conditions_fo_successful_Urban_Living_Labs.pdf (accessed December 10, 2023).

Finnveden, G., Djupström, M., Hörstedt, F., and Von Oelreich, K. (2022). "The climate framework for higher education institutions in Sweden," in *Handbook of best practices in sustainable development at university level*, eds L. F. von Walter and C. R. P. de Vasconcelos (Cham: Springer Nature), 151–171. doi: 10.1007/978-3-031-04764-0

Grant, M. J., and Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Inf. Libraries J.* 26, 91–108.

Greve, K., Leminen, S., Vita, R. D. E., and Westerlund, M. (2020). Unveiling the diversity of scholarly debate on living labs: A bibliometric approach. *Int. J. Innov. Manag.* 24:2040003. doi: 10.1142/S1363919620400034

Henríquez Guajardo, P. (2018). *El papel estratégico de la educación superior en el desarrollo sostenible de América Latina y el caribe. Herausgegeben von pedro henríquez guajardo und hugo juri*. Caracas: Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura.

Hernández-Diaz, P. M., Polanco, J.-A., Escobar-Sierra, M., and Filho, W. L. (2021). Holistic integration of sustainability at universities: Evidences from Colombia. *J. Clean. Prod.* 305:127145.

Huertas, J. I, Mahlknecht, J., Lozoya-Santos, J. J., Uribe, S., López-Guajardo, E. A., and Ramirez-Mendoza, R. A. (2021). Campus city project: Challenge living lab for smart cities. *Appl. Sci.* 11:1085. doi: 10.3390/app112311085

Hugo, H., Espinoza, F., Morales, I., Ortiz, E., Pérez, S., and Salcedo, G. (2018). Delta project: Towards a sustainable campus. *Sustainability* 10:3695. doi: 10.3390/su10103695

ITESO, and Universidad Jesuita de Guadalajara (2023). *Urban lab guadalajara*. Tlaquepaque: ITESO.

Jorge, T. L. (2023). *UrbanLab Bogotá región*. Bogotá: Universidad de Bogotá.

Juujärvi, S., and Pesso, K. (2013). Actor roles in an urban living lab: What can we learn from suurpelto, Finland? *Technol. Innov. Manag. Rev.* 3, 22–27.

Koppers, R. (2015). *Implementing living labs in regulations: A case study of the realization of The Green Village*. Utrecht: Utrecht University.

Korzer, T., Hubscher, M., Schade, K., and Ringel, J. (2020). Rethinking retail digitisation in urban settings. The case of leipzig, Germany. *Proc. Inst. Civil Eng.* 173, 197–209. doi: 10.1680/jurdp.19.00019

Kronthaler, F., and Zöllner, S. (2021). Data analysis with RStudio. *Easyg. Introd.* 5, 7–131.

Leal Filho, W. (2018). "Implementing sustainability in the curriculum of universities approaches, methods and projects," in *Implementing sustainability in the curriculum of universities approaches, methods and projects*, ed. W. Leal Filho (Cham: Springer).

Leal Filho, W., and Dahms, L.-M. (2018). *incorporating sustainable development issues in teaching practice BT – implementing sustainability in the curriculum of universities: Approaches, methods and projects*. Cham: Springer International Publishing, 323–330. doi: 10.1007/978-3-319-70281-0_20

Leal Filho, W., Emblen-Perry, K., Molthan-Hill, P., Mifsud, M., Verhoef, L., Azeiteiro, U. M., et al. (2019). Implementing innovation on environmental sustainability at universities around the world. *Sustainability* 11:3807.

Leicht, A., Heiss, J., and Byun, W. J. (2018). *Issues and trends in education for sustainable development*, ed. 5 Edn. Paris: UNESCO Publishing.

Lozano, R., Lukman, R., Lozano, F. J., Huisingh, D., and Lambrechts, W. (2013). Declarations for sustainability in higher education: Becoming better leaders, through addressing the university system. *J. Clean. Prod.* 48, 10–19. doi: 10.1016/j.jclepro.2011.10.006

Mahmoud, I., and Morello, E. (2021). "Co-creation pathway for urban nature-based solutions: Testing a shared-governance approach in three cities and nine action labs," in *Proceedings of the 3rd international conference on smart and sustainable planning for cities and regions, SSPCR 2019. Laboratorio di simulazione urbana fausto curti, dipartimento di architettura e studi urbani, politecnico di Milano, via Bonardi 3, Milano, 20133*, eds A. von Visvizi, M. D. Lytras, and N. R. Aljohani (Berlin: Springer Science and Business Media Deutschland GmbH), doi: 10.1007/978-3-030-57764-3_17

Marvin, S., Bulkeley, H., Mai, L., McCormick, K., and Palgan, Y. V. (2018). "Urban Living Labs," in *Urban living labs: Experimenting with city futures*, eds M. von Simon, H. Bulkeley, L. Mai, K. McCormick, and Y. V. Palgan (Milton Park: Routledge), doi: 10.4324/9781315230641

Masseck, T. (2017). Living labs in architecture as innovation arenas within higher education institutions. *Energy Proc.* 115:35. doi: 10.1016/j.egypro.2017.05.035

Matas, A. (2018). Likert-type scale format design: State of art. *Rev. Electr. Invest. Educ.* 20, 38–47.

Mavrou, I. (2015). Análisis factorial exploratorio: Cuestiones conceptuales y metodológicas. *Rev. Nebrija Ling. Apl. Enseñanza Leng.* 19, 71–80.

McCormick, K., and Hartmann, C. (2017). The emerging landscape of urban living labs characteristics, practices and examples. *Governance Urban Sustain. Trans.* 7, 1–20.

McCormick, K., and Kiss, B. (2015). Learning through renovations for urban sustainability: The case of the Malmö innovation platform. *Curr. Opin. Environ. Sustain.* 16, 44–50.

MK:Smart (2024). Available online at: https://www.mksmart.org/about/ (accessed November 15, 2021).

Morales, I., Segalàs, J., and Masseck, T. (2023). Urban living labs: A higher education approach to teaching and learning. *Sustain. Dev.* 15, 1–20. doi: 10.3390/su152014876

Moreno, Y., Ángeles, M., and Martínez, M. J. B. (2015). Análisis de los procesos educativos y organizativos para la sostenibilidad: Una propuesta de cambio. *Foro Educ.* 13, 35–53. doi: 10.14516/fde.2015.013.019.003

Mori, R., Fien, J., and Horne, R. (2019). Implementing the UN SDGs in universities: Challenges, opportunities, and lessons learned. *Sustainability* 12, 129–133. doi: 10.1089/sus.2019.0004

O'Brien, W., Doré, N., Campbell-Templeman, K., Lowcay, D., and Derakhti, M. (2021). Living labs as an opportunity for experiential learning in building engineering education. *Adv. Eng. Inf.* 50:101440. doi: 10.1016/j.aei.2021.101440

Organización de las Naciones Unidas para la Educación [UNESCO] (2017). *Educación para los objetivos de desarrollo sostenible. Objetivos de aprendizaje*. Paris: UNESCO.

Paço, A. D., and Azeiteiro, U. M. (2022). *Living labs for education for sustainable development in the context of higher education: Identifying triggers and drivers of development in the Portuguese Universities; Higher education institutions in a global warming world*. Denmark: River Publishers, 155–170.

Pérez, M. A. (2013). La energía en los espacios públicos caso de estudio: Ciudad universitaria de la UNAM. *Rev. Semestral Invest.* 4, 11–23.

Purcell, W. M., Henriksen, H., and Spengler, J. D. (2019). Universities as the engine of transformational sustainability toward delivering the sustainable development goals. *Int. J. Sustain. High. Educ.* 20, 1343–1357. doi: 10.1108/IJSHE-02-2019-0103

Rieckmann, M. (2017). *Education for sustainable development goals: Learning objectives*. Paris: UNESCO publishing.

Rizzo, A., Habibipour, A., and Ståhlbröst, A. (2021). Transformative thinking and urban living labs in planning practice: A critical review and ongoing case studies in Europe. *Eur. Plann. Stud.* 29, 1739–1757. doi: 10.1080/09654313.2021.1911955

Rotondo, F., Giovanelli, L., and Ezza, A. (2023). Implementing sustainable innovation in state universities: Process and tools. *J. Clean. Prod.* 391:136163. doi: 10.1016/j.jclepro.2023.136163

Santo Tomás Universidad (2023). *Innovalab, espacios colaborativos de innovación social*. Bogotá: Santo Tomás Universidad.

Sao Paulo Universidad (2023). *Laboratorio para otros urbanismos*. Butantã: Sao Paulo Universidad.

Schäpke, N., Stelzer, F., Caniglia, G., Bergmann, M., Wanner, M., Singer-Brodowski, M., et al. (2018). Jointly experimenting for transformation?: Shaping real-world laboratories by comparing them. *GAIA* 27, 85–96. doi: 10.14512/gaia.27.S1.16

Schliwa, G. (2013). *Exploring living labs through transition management-challenges and opportunities for sustainable urban transitions*. Lund: IIIEE.

Scholl, C., and de Kraker, J. (2021). Urban planning by experiment: Practices, outcomes, and impacts. *Urban Plann.* 6, 156–160. doi: 10.17645/up.v6i1.4248

Segalàs, J. (2019). El proyecto EDINSOST. *Formación Univers. Esp. Profes. Agent. Cambio Para Afrontar Soc.* 1, 1–16.

Sengers, F., Wieczorek, A. J., and Raven, R. (2019). Experimenting for sustainability transitions: A systematic literature review. *Technol. Forecast. Soc. Change* 145, 153–164. doi: 10.1016/j.techfore.2016.08.031

Sinakou, E., Donche, V., and Van Petegem, P. (2022). Action-orientation in education for sustainable development: Teachers' interests and instructional practices. *J. Clean. Prod.* 370:133469. doi: 10.1016/j.jclepro.2022.133469

Skanavis, C., Kounani, A., Tsamopoulos, K., Polymeris-Maripas, G., Koukoulis, A., Topaltsis, L., et al. (2020). "Implementing sustainable development through environmental camps: The case of skyros project," in *Proceedings of the universities and sustainable communities: Meeting the goals of the agenda 2030*, eds W. Leal Filho, U. Tortato, and F. Frankenberger (Berlin: Springer), 805–823. doi: 10.1007/978-3-030-30306-8_52

Steen, K., and Bueren, E. (2017). The defining characteristics of urban living labs. *Technol. Innov. Manag. Rev.* 7, 21–33. doi: 10.1016/j.ajem.2017.10.015

Sterling, S. R., and Orr, D. (2001). *Sustainable education: Re-visioning learning and change*, ed. 6 Edn. Totnes: Green Books for the Schumacher Society Totnes.

Sterling, S., and Thomas, I. (2006). Education for sustainability: The role of capabilities in guiding university curricula. *Int. J. Innov. Sustain. Dev.* 1, 349–370.

Tilbury, D. (2011). Higher education for sustainability: A global overview of commitment and progress. *High. Educ. World* 4, 18–28.

UNALAB (2017). *UNALAB El proyecto UNaLab está contribuyendo al desarrollo de ciudades más inteligentes, inclusivas, resilientes y cada vez más sostenibles a través de la implementación de soluciones basadas en la naturaleza*. Available online at: https://unalab.eu/en (accessed November 30, 2021).

Van Balen, K. (2021). "The 10th anniversary of the PRECOM3OS UNESCO Chair," in *Proceedings of the 2020 future of the past: Paths towards participatory governance for cultural heritage*, eds G. von Garcia, A. Vandesande, F. Cardoso, and K. Van Balen (Belgium: CRC Press/Balkema), 17–26. doi: 10.1201/9781003182016-3

Van Geenhuizen, M. (2019). Applying an RRI Filter in key learning on urban living labs'. *Perform. Sustain* 11:3833. doi: 10.3390/su11143833

Van Wijk, A. (2013). *Welcome to the green village*. Amsterdam: IOS Press.

Verhoef, L. A., Bossert, M., Newman, J., Ferraz, F., Robinson, Z. P., Agarwala, Y., et al. (2020). "Towards a learning system for university campuses as living labs for sustainability," in *Universities as living labs for sustainable development. World sustainability series*, eds W. Leal Filho, A. L. Salvia, R. W. Pretorius, L. L. Brandli, E. Manolas, F. Alves, et al. (Cham: Springer International Publishing), 135–149. doi: 10.1007/978-3-030-15604-6_9

Von Wirth, T., Frantzeskaki, N., and Loorbach, D. (2020). Urban living labs as inter-boundary spaces for sustainability transitions? *Handb. Plann. Complex.* 85, 237–257. doi: 10.4337/9781786439185.00017

Von Wirth, T., Fuenfschilling, L., Frantzeskaki, N., and Coenen, L. (2019). Impacts of urban living labs on sustainability transitions: Mechanisms and strategies for systemic change through experimentation. *Eur. Plann. Stud.* 27, 229–257. doi: 10.1080/09654313.2018.1504895

Voytenko, Y., McCormick, K., Evans, J., and Schliwa, G. (2016). Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. *J. Clean. Prod.* 123, 45–54. doi: 10.1016/j.jclepro.2015.08.053

Wallin, S. (2014). *The urban living lab: Guidelines for APRILab. APRILab: Action oriented research on planning, regulation and investment dilemmas in a living lab experience*. Amsterdam: AMS Institute.

Wals, A. E. J. (2014). Sustainability in higher education in the context of the UN DESD: A review of learning and institutionalization processes. *J. Clean. Prod.* 62, 8–15.

Withycombe Keeler, L., Wiek, A., Lang, D. J., Yokohari, M., van Breda, J., Olsson, L., et al. (2016). Utilizing international networks for accelerating research and learning in transformational sustainability science. *Sustain. Sci.* 11, 749–762. doi: 10.1007/s11625-016-0364-6

Wolff, P. J. (2020). "Adventure cards, process wheels, and a vision for digital storytelling: Learning from Leonardo," in *Universities as living labs for sustainable development: Supporting the implementation of the sustainable development goals*, eds W. Filho, A. Lange Salvia, R. W. Pretorius, L. L. Brandli, E. Manolas, F. A. Ulisses Azeiteiro, et al. (Cham: Springer International Publishing), 417–433. doi: 10.1007/978-3-030-15604-6_26