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ORIGINAL ARTICLE

Living labs in the context of the UN sustainable development goals: state of the art

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Abstract
This paper reports on a comprehensive study, which has investigated the approaches, methods and tools being deployed in implementing living labs among higher education institutions (HEIs) around the world. Two methods were employed. First, a bibliometric analysis of the current emphasis given to living labs in a sustainable development context and in the implementation of the Sustainable Development Goals (SDGs). Second, an empirical study aimed at identifying the use levels of living labs at HEIs. This was accomplished through an analysis of selected case studies that showcased successful approaches to SDGs implementation with living labs, and resulted in a framework for action. There are three main findings from these analyses. The first is that the multidisciplinary character of living labs in the context of sustainable development needs to be considered, to maximize their impacts. Second, most of the studied living labs focus on SDGs 4 and 11, which deal with providing quality education and ensuring the sustainable development of cities and communities. Third, the challenges encountered in the implementation of living labs refer to (1) the complexities in institutional administration, (2) the tensions between different groups of interest that need to be addressed by enhanced communication, and (3) the necessity to pay attention to the demand of using sustainability and innovation as a strategy in the operations of living labs. The paper draws from the experiences and lessons learned and suggests specific measures, which will improve the use of living labs as more systemic tools towards the implementation of the SDGs.

Keywords Innovation · Collaboration · Academic research · Learning opportunities · Institutional sustainability profile

Introduction: the 'living labs' concept

Scholarly studies about 'living labs' have emerged in the past 10 years as a novel strategy for spurring innovation opportunities in education for sustainability. The concept was first explored in 1990 by Bajgier et al. (1991) to describe students' experimental activities in a large city neighbourhood of Philadelphia, Pennsylvania, to assist with problems that challenged that community. The concept has further evolved as an approach to solving complex social crises by developing, testing, and refining new technologies (Mitchell 2003). In 2006, the European Union introduced a definition of this term through the European Network of Living Labs (ENoLL), which was inclusive of integrating research and innovation processes in real community settings (https://enoll.org/). However, the definition ("variety of local experimental projects of a participatory nature") proposed by Steen and van Bueren (2017a, p. 22) in the urban context remains most valuable to researchers, because it establishes a clear understanding of the possibilities offered by living labs and demonstrates what can be expected from these. According to Mulder et al. (2008), living labs should be considered from various perspectives to enable interoperability between setup, sustainability, and scalability. Additional frameworks exist to highlight characteristics of living labs, as shown in Table 1.

According to Nystrom et al. (2014), living labs can be conceived also as networks of inclusive innovation that are shaped by the roles of each participant. Also, living labs are

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Table 1 Living labs characteristics from a sample of frameworks, in chronological order

Living lab characteristics	References
Users' involvement Service creation Infrastructure Governance Innovation outcomes Methods tools (include support for new technologies)	Mulder et al. (2008)
Geographical embeddedness Experimentation and learning Users' engagement Leadership–ownership Evaluation	Voytenko et al. (2016)
Innovation and formal learning Development, co-creation and iteration All participants with decision-making power Real-life use context	Steen and van Bueren (2017a)
Real-life environments Stakeholders' activities Business models Networks Methods, tools, and approaches Challenges Incremental outcomes Sustainability (smart urban development)	Hossain et al. (2019)

Stakeholders/users′ involvement remained a consistent trait of living labs through time

grounded in sustainability, crossing diverse fields of knowledge and interests. These span innovation, applicable to smart urban environments, through the promotion of intelligent network technologies (Bakıci et al. 2013; Leal Filho et al. 2022a); explorations of real-time local settings, that nurture best practices in sustainable development (Nevens et al. 2013); and assessments of their role in transformative change on how they can optimize socio-material conditions while ensuring agency and allocating resources (Bulkeley et al. 2016).

Despite this broad use of the concept, an increasing interest in living labs perceived as assets to achieve the Sustainable Development Goals (SDGs) (United Nations General Assembly 2015) has been increasing consistently, through the years. The latest studies have focused on how living labs can contribute to promoting local, urban entrepreneurship (Rodrigues and Franco 2018) that fosters sustainability, and social and economic development (Leal Filho et al. 2022b; Voytenko et al. 2016). Living labs have gained wide attention in academia also for how universities and their academic communities become key drivers in transferring knowledge and innovation to society, through citizens' outreach education initiatives (Purcell et al. 2019; Findler et al. 2019; Stephen et al. 2008). Thus, a living lab can be a powerful learning and action tool to foster students' participation in projects organized at the community level, while bringing together stakeholders with different areas of expertise. This interaction expands opportunities for enhancing knowledge in sustainability through participatory research (Rosenberg Daneri et al. 2015).

Higher Education Institutions (HEIs) have the potential to become effective tools of transformation towards sustainability through living labs, legitimizing the need for research studies with such a focus, where these are already established in higher education settings. In addition, investigations about the methods employed in pursuit of a successful implementation of the SDGs are urgently needed to fill in this knowledge gap. Consistent with these requirements, this paper aimed at assessing the connections between living labs and sustainable development. Our assessment study was accomplished through a two-pronged strategy, which included a bibliometric analysis and an analysis of selected case studies from HEIs around the world. Our findings promote a better understanding of the role of living labs for sustainable development, while presenting current approaches being employed by some universities and shedding light on this compelling topic.

Living labs and sustainable development

Universities have the potential to play a key role in supporting the implementation of the SDGs. By working in partnership with students, employees, stakeholders, and the external community, universities can pursue ingenious solutions, which can provide economic, social, and environmental benefits for both the university and the community (Purcell et al. 2019; Sroufe 2020).

Against this background, the setup of living labs as tools to support the implementation of the SDGs can be a useful tool. In

addition to catering to greater interaction and cooperation among the various actors, living labs may act as a bridge between open innovation and the users of these innovations, within a sustainability context (Compagnucci et al. 2021; Burbridge 2017a, b). Another characteristic of living labs is that they can contribute to raising awareness of practices aimed at sustainability through the development of pilot projects, making the university campus become an 'intelligent campus'. This, in turn, ensures that universities become more connected with society, particularly within a sustainability context (Mazutti et al. 2020a, b).

Rowan and Casey (2021) presented the importance of the living lab 'Empower Eco-sustainability HUB', which counts on the participation of academia, the civil community, companies, industries, and policymakers. Green innovations are developed within a triple helix context (industry–university–government agencies), that seeks to promote the implementation of the European Green Deal, whose aim is to transform Europe into an economically sustainable region (Cerreta et al. 2020). Many projects developed within a living labs context allow students to become directly involved in practices aimed at achieving sustainable development. Using living labs-oriented practices, universities can not only engage in consuming resources efficiently but also reduce their carbon footprint (Leal Filho et al. 2021), based on learning experiences that include the participation of both internal and external members of the academic community (Amorim et al. 2020). According to Sierra-Pérez and López-Forniés (2020), living labs may also focus on fostering the pursuit of the SDGs in urban centres, by tackling issues related to a circular economy, urban mobility, sustainable urban planning, waste management, renewable energies, and sustainable consumption, among others. Also, climate change is among the issues which may be pursuable via a living labs approach, fostering both adaptation and mitigation practices (Leal Filho et al. 2021).

By supporting the pursuit of the SDGs in urban centres, living labs can also contribute towards the following aims (Voytenko et al. 2016; von Wirth et al. 2019):

- exploring the political dilemmas that limit innovation in cities,
- fostering a greater understanding of how to promote sustainable consumption, through stakeholders' engagement, and developing knowledge and tools to maximise the use of green and blue infrastructure,
- examining how suburbs can be modernized and socially uplifted to make them more attractive, sustainable and economically viable, and
- developing guidelines on the means via which living labs can be better integrated into formal local government organizations.

So, according to Baran and Berkowicz (2020), living labs that focus on sustainability can lead to the creation of innovation and experimentation, which can then be converted into solutions for tangible economic, environmental, and social problems. As social behaviour is based on environmental and cultural contexts, living labs can be effective supporting tools, fostering knowledge integration, and the formulation of new questions for issues addressing sustainability (Heilmann and Pundt 2021).

Methods: existing approaches to living labs

The aim of this study is to investigate the approaches, methods and tools being deployed in implementing living labs among HEIs around the world. Apart from a bibliometric analysis of current emphases given to living labs' approaches to sustainable development for an implementation of the SDGs, the work entails an empirical study aimed at identifying their levels of deployment and introduces a set of case studies where successful approaches are showcased. The study encompasses two main research questions:

1. What is the role of living labs in a sustainability context?
2. Which living lab approaches are being currently used by universities?

The bibliometric review was carried out through a science mapping approach to review research on experiences related to living labs deploying or boosting the SDGs. Hallinger and Chatpinyakoop (2019, p. 1) conceded that "research reviews grounded in bibliometric methods do not examine the substantive finds of studies. Rather, their value extends from the capability to document and synthesize broad trends that describe the landscape composing and intellectual structure of a knowledge base". Thus, the scientific mapping approach was performed with the aim of illuminating trends in knowledge building on the researched topic. The bibliometric review was performed on the core collection of Web of Science (WoS) on April 2021, using the combination of the two following search strings, with English as the publication language, and no restrictions in terms of the type of publication and timeframe:

- "living lab*" AND "sustainable development" = 61 results
- "living lab*" AND "sustainability" = 215 results

The combination of the two searches, eliminating duplicates, resulted in 234 publications. These were screened through the reading of the title, abstracts, and keywords to remove references not related to the specific field of study. In this phase, 18 references were eliminated before performing the mapping process through the software VOSviewer (Van Eck and Waltman 2010). The bibliometric analysis

comprised the investigation of (a) co-occurrences in keywords, (b) the most prominent journals, (c) the most active authors.

Based on the available literature, a set of 20 case studies was chosen to illustrate how the living labs approach is being pursued for the implementation of the SDGs. Besides the description of each case and its connection with the SDGs (Table 4), a framework for action was also designed (Fig. 3). This framework represents an additional strategy to provide support and deepen the knowledge regarding existing approaches to living labs at universities and their contribution to the 2030 Agenda, and offers some key information about the challenges to be met, and outcomes to be reached, beyond the context of HEIs.

Results and discussion

Bibliometric analysis

(a) Keyword co-occurrences

The co-occurrence map shows the most common keywords used in the analysed search and a visual representation of the network connections of keywords that appear more frequently in the documents analysed (Cancino et al. 2017, p. 620; Shi et al. 2019). As explained by Guo et al. (2019), keyword bursts refer to those keywords which rise sharply in citations. Burst detection is a suitable analytic method to uncover the keywords that receive particular attention from the related scientific communities in each period. The sample composed of 216 references provided 377 keywords, from which 32 were selected for meeting the threshold of a minimum of 3 co-occurrences. The keywords co-occurrence network is formed by the group of references that have at least 3 equal keywords in each paper (Su and Lee 2010). Those 32 keywords were grouped into 4 clusters, as shown in Fig. 1.

The first cluster, in red and composed of 11 keywords, is strongly represented by the keyword "innovation", which has the highest link strength in the cluster (103), occurring 38 times in the sampled references. The second cluster, in green, has 10 keywords and is represented by "sustainability", which is the most representative keyword with the highest total link strength (95), occurring 37 times. The next cluster, in blue, is represented by the keyword "framework", which has a total link strength of 44, with 17 occurrences. In addition to the visual representation of these results in Fig. 1a, Table 2 shows the keywords compiled in the sampled references with occurrences greater than or equal to 10. These are the most used keywords to describe the field of research formed by the interconnection between living labs and the SDGs.Regarding the time frame of publications and the use of keywords (Fig. 1a), specific terms such as "technology", "consumption", and "science", illustrated in the figure in dark blue circles, are considered consolidated and mature keywords to designate broad studies in the field of living labs and the SDGs. On the other hand, keywords such as "energy" and "urban living labs", shown in yellow, Fig. 1b, are more recently cited in the literature, evidencing the up-to-date use of those keywords in the field. Finally, the keywords illustrated in bigger sizes and shades of green represent items at the intermediate stage of evolution and adoption as a keyword for the analysed field of study. Thus, the analysis of the different sizes and colours of the circles presented in Fig. 1 provides valuable insights into the dynamics, relevance, and evolution of the living labs and SDGs, studied in the analysed period.

(b) The most prominent sources

From our sample of 216 publications, 125 sources were found and, of these, five met the minimum threshold of 5 identified documents from the source. Thus, the five leading sources in publishing documents regarding living labs and the SDG are shown in Table 3. The results show three scientific journals and two books. The scientific journal that stands out in terms of number of documents is *Sustainability*, contributing with 33 documents, followed by the *International Journal of Sustainability in Higher Education* and the *Journal of Cleaner Production*, both with nine documents.

The results draw attention to the cross-disciplinary profile of the analysed field of study, evidenced by the variety of sources that publish more articles on living labs and the SDGs. The *Journal of Cleaner Production* stands out as one of the most influential, given the number of citations and its Impact Factor.

In the analysed database, the paper by Evans et al. (2015) published by the journal *Sustainability*, stood out as a prominent referent for having been cited 87 times. The work intends to discuss the potential of living labs to provide a holistic and iterative framework for the co-production of knowledge. The living labs initiative was introduced in 2012 to render the University of Manchester campus into a place for applied teaching and research activities related to sustainability. This article published by *Sustainability* also discussed the generalization of living lab projects, and the design of HEIs as a living lab, and pointed out the main strengths and challenges of living labs approaches. Voytenko et al. (2016), cited 166 times, was another influential reference published by the *Journal of Cleaner Production*. In order "to develop current understandings through an examination of how the living labs concept is

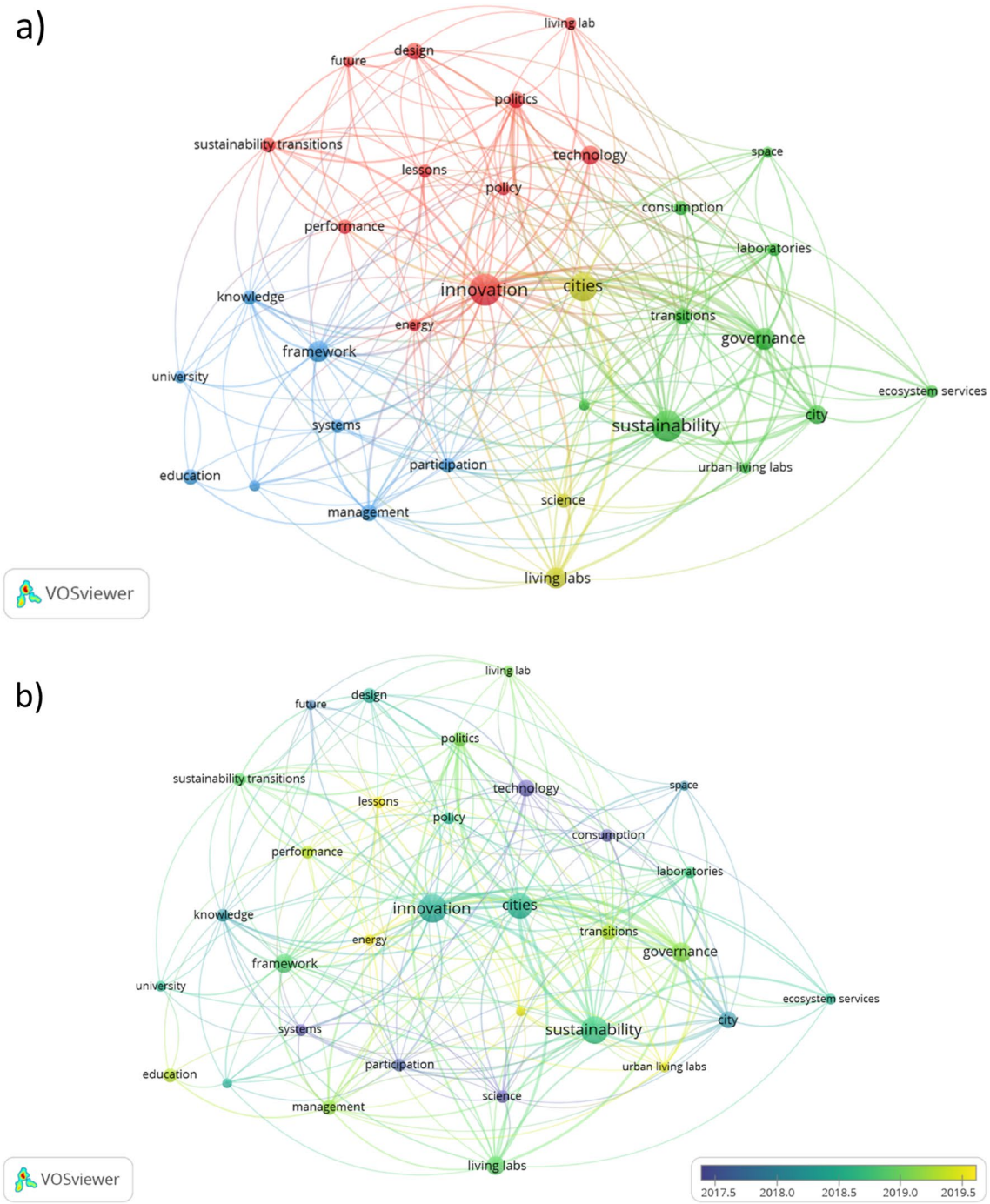

Fig. 1 Co-keyword network and overlap visualizations of living labs and SDGs. **a** Co-keyword network visualization of living labs and SDGs, based on occurrences; **b** co-keyword overlay visualization, based on the score of occurrences and average publication per period

being operationalized in contemporary urban governance for sustainability and low carbon cities", the authors identified the following five key urban living labs characteristics: geographical embeddedness, experimentation and learning, participation and user involvement, leadership and ownership, and evaluation and refinement (Voytenko et al. 2016, p. 45). Finally, it is worth highlighting the contribution of the book "Universities as Living Labs for Sustainable Development: supporting the implementation of the SDGs", by Leal Filho et al. (2020), which assisted in filling the knowledge gaps in the field of universities as living labs towards sustainable development, as it documented, in its 52 chapters, best practices of university experiences from all around the world.

Table 2 Most frequent keywords in the field of living labs and the SDGs (co-keywords with occurrences equal to or greater than 10) (Note: data from April 2021)

Ranking	Cluster	Keyword	Occur.[a]	TLS[b]	Ranking	Cluster	Keyword	Occur.[a]	TLS[b]
1	1	Innovation	38	103	7	2	City	14	46
2	2	Sustainability	37	95	8	1	Technology	13	24
3	4	Cities	30	89	9	3	Management	11	32
4	2	Governance	19	72	10	1	Politics	11	49
5	3	Framework	17	44	11	1	Design	10	24
6	4	Living labs	17	46	12	2	Transitions	10	43

[a]Occurrences

[b]Total link strength

Table 3 The most active sources publishing in the field of living labs and the SDGs (ranked by number of citations) (Note: data from April 2021)

Source title	Documents	Citations	TLS[a]	IF[b]
Journal of Cleaner Production	9	266	29	7.246
Sustainability	33	119	28	2.576
International Journal of Sustainability in Higher Education	9	110	12	2.000
Universities as Living Labs for Sustainable Development: supporting the implementation of the SDGs	15	11	4	–
Towards Green Campus Operations: energy, climate, and sustainable development initiatives at universities	7	6	1	–

[a]Total link strength

[b]Impact factor

(iii) The most active authors

The module of the co-authorship analysis in VOSviewer (Van Eck and Waltman 2010) was applied to examine the cooperation pattern among the authors. The sample comprises 747 co-authors and only 54 meet the established threshold of a minimum number of documents equal to, or greater than, 2. Figure 2 illustrates the 14 most prominent authors, divided into four clusters. This citation analysis shed light on the influential scholars in producing knowledge in the field of living labs related to the SDGs. In Fig. 2, lines among authors represent their cooperation links, while the different colours represent the four clusters identified in the analysis.These results indicate that the most productive author is Frantzeskaki Niki, a Professor at the Swinburne University of Technology, Melbourne, Australia. She works in the field of urban sustainability, has seven documents in the sample of references, and has a total link strength of 21 (Bulkeley et al. 2019; von Wirth et al. 2019). This author is followed by Yuliya Voytenko Palgan, from the International Institute for Industrial Environmental Economics (IIIEE), at Lund University, Sweden, and Timo von Wirth who is an Assistant Professor at Erasmus School of Social & Behavioural Sciences, Netherlands. Both have five documents cited in the sample and research the field of urban living labs (Bulkeley et al. 2016, 2019; Menny et al. 2018; von Wirth et al. 2019).

Case studies

Examples of living labs can be found in different domains of knowledge-related areas, from biosphere reserves (Hugé et al. 2020), to smart cities planning (Counsell 2017; Kirwan and Zhiyong 2020; Papadopoulou and Giaoutzi 2017; Putra and van der Knaap 2019), urban development (Engez et al. 2021) and urban environment (Smaniotto Costa et al. 2020), and in particular within the scope of HEIs, known for their promotion of education and actions in sustainable development (Leal Filho and Surroop 2018; Mazutti et al. 2020a, b; Sroufe 2020). The multi-disciplinarity and multi-dimensionality of education and research regarding global issues (O'Neill 2003; Shao et al. 2011) have long been pursued by HEIs. With the onset of the SDGs, the need for such an approach has amplified, making the living labs concept become more urgent for HEIs as setting a medium for multi-disciplinarity and multi-dimensionality. In this respect, living labs differ among HEIs, as these are used as testbeds and university stakeholders are regarded as test subjects (Engels et al. 2019).

Accordingly, the key aspects to be addressed in this subsection aim to illustrate a wide range of living labs at HEIs and their importance for achieving the SDGs, with a selection of 20 case studies that exemplify how living labs in HEIs may contribute to successfully foster overall sustainable development worldwide. Table 4 presents 20 case

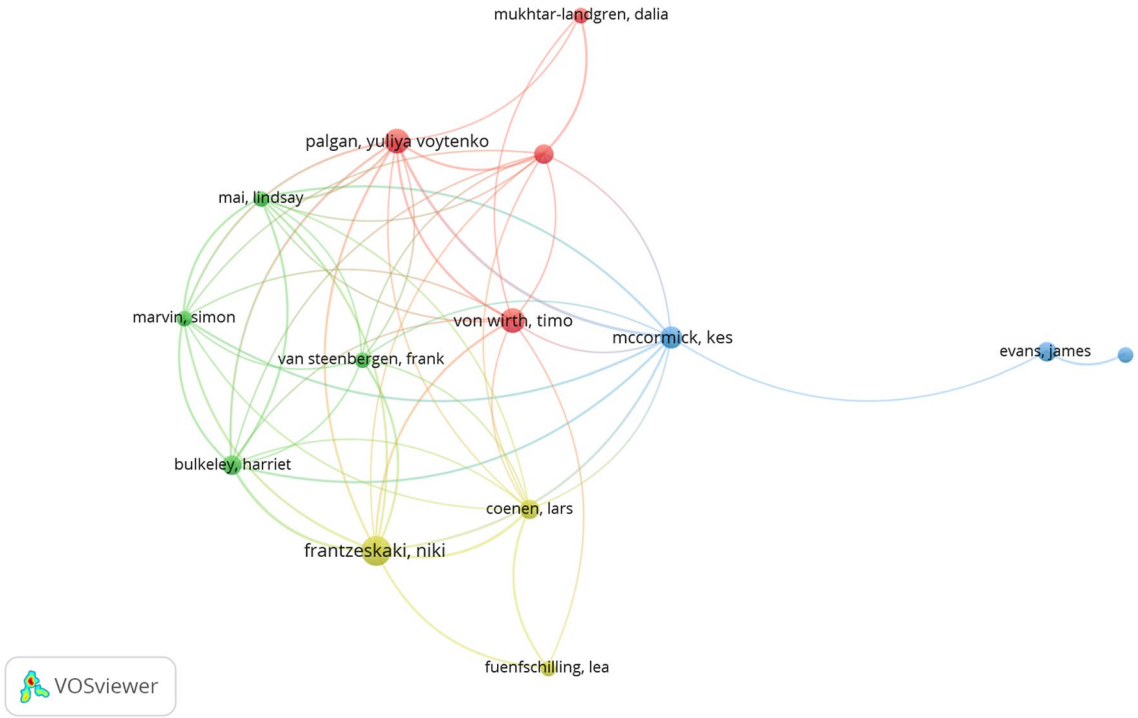

Fig. 2 Authors' cooperation network

studies addressing living labs within HEIs that illustrate achievements towards specific SDGs. These efforts focused on HEIs which draw on both top-down and bottom-up strategies to accomplish transformative institutional changes (Purcell et al. 2019). While most efforts developed by HEIs in applying the concept of living labs on their campuses involve the commitment to energy initiatives (SDG7), climate change (SDG13), or quality education (SDG4), the addressed case studies presented in Table 4 are committed to several SDGs, to a greater or lesser extent, as presented and discussed below.

The cases of Plymouth University, American University in Bulgaria, Macalester College and the University of Tasmania can be highlighted. Whereas at Plymouth University the focus is on the engagement of students with the wider civic and business communities (Plymouth 2019; Purcell et al. 2019), at Macalester College the living lab approach involves partnering with key participants and with industry for a joint engagement in wider sustainability efforts, thus moving beyond the individual class paradigm and incorporating projects into classes (Hansen 2017). At the American University in Bulgaria (Purcell et al. 2019), the experience leads to business value creation and to the promotion of societal impact, including environmental protection and restoration. On the other hand, the efforts made through the centre of expertise Education for Sustainability Tasmania (EfSTas) represent an experimental test bed to explore new models of sustainability principles and practice, promoting collaboration between students, researchers, and the community in resolving regional challenges (Emery et al. 2020).

Several initiatives have been fostering the energy and climate goals (SDGs 7 and 13). In Germany, the Hamburg and Stuttgart Universities of Applied Sciences have dedicated examples of engagement with the academic community and promotion of renewable energy and energy efficiency, with demonstration and transferable character (Botero et al. 2017; Leal Filho and Surroop 2018). Similarly, the living lab LAB LOW3 at the Polytechnic University of Catalonia fosters teaching and research activities in solar architecture, as well as in building simulations and scientific field assessment (UPC, n.d.). The Sustainable Energy Campus at the University of Lisbon promotes the use of smart resources to reduce electricity consumption and to promote socially responsible actions (Ferrão and de Matos 2017). The University of British Columbia (Save et al. 2021; UBC, n.d.) and the Chatham University Eden Hall Campus (Walker and Mendler 2017) operate with wider scopes. The former works as a living lab with its academic campuses and integrated residential neighbourhoods to test innovative solutions, expand a bioenergy facility, and contribute to several local policies (e.g., the 20-year Sustainability Strategy, the Climate Action Plan, and the Green Building Action Plan), whereas the latter is the first university campus designed to demonstrate sustainable solutions and train students while engaging with the local community.

Table 4 Selection of case studies on living labs at HEIs

Case	University	Country	Short description	Addressed SDGs	References
1	Hamburg University of Applied Sciences	Germany	Experimenting with renewable energy on a campus: Set-up of the "Energy Campus" at HAW Hamburg, where research and deployment of renewable energy techniques and methods are pursued and demonstrated		Leal Filho and Surroop (2018)
2	Plymouth University	United Kingdom	Sustainability as a lens through the university's teaching, research, operations, and community service: mission-led transformation based on the concept of enterprise and sustainability as key to institutional health over the long term, committing to transforming lives through education and research		Purcell et al. (2019) Plymouth (2019)
3	American University in Bulgaria	Bulgaria	Reframe sustainability as a strategic agenda, aligning business goals with the SDG Framework: Stakeholder partnership of businesses with the University, creating a "living lab" to explore creative solutions involving deep knowledge and experience of whole organizational change and sustainability		Purcell et al. (2019)
4	Harvard University	USA	Sustainability plan around a holistic vision and clear university-wide goals from emissions and energy, campus operations, nature and ecosystems, health and well-being, and culture and learning: Innovation to address problems threatening the health of people and planet, working on the ground and across disciplines, co-funding projects and acting as a convener and connector as well as adviser, trainer, mentor, and coach to those involved in shared projects		Purcell et al. (2019) Harvard (n.d.)
5	Stuttgart University of Applied Sciences	Germany	Transdisciplinary research methods to find transferable solutions for the transition to a climate-neutral inner-city campus—Ensign Lab: development of an iterative, optimization-based, knowledge capture process that is inclusive of both external and internal stakeholders		Botero et al. (2017)
6	Macalester College	USA	Living laboratory program through teaching classes, working with environmental studies faculty, and assisting faculty in incorporating projects into existing classes		Hansen (2017)
7	University of Lisbon	Portugal	Sustainable Energy Campus: A Challenge on Smart Facilities and Operations—Sustainable Campus at Técnico project was set in motion to improve the overall energy efficiency within the Instituto Superior Técnico facilities, through new auditing tools and thermal computational models of all campus buildings		Ferrão and de Matos (2017)
8	Chatham University Eden Hall Campus	USA	Creating a Sustainable Campus from the Ground up First new university campus in the world to be built sustainably from the ground up, featuring full cycle water recycling, net positive energy production, and zero waste operations in an immersive living and learning environment for residential students		Walker and Mendler (2017)

Table 4 (continued)

Case	University	Country	Short description	Addressed SDGs	References
9	University of British Columbia	Canada	Campus as a Living Lab (CLL) Program to Promote Sustainable Practices: Use of a Campus as a Living Lab to marry industry, campus operations, and research to drive innovative solutions aiming for major district energy upgrade and a bioenergy facility		Save et al. (2021) UBC (n.d.)
10	Polytechnic University of Catalonia	Spain	Living Labs in Architecture as Innovation Arenas within higher education institutions: prototype solar house designed, built, converted, and operated as a Living Lab for sustainable architecture and lifestyle, research regarding pluridisciplinary, experience-based sustainability education		Masseck (2017)
11	University of Manchester	United Kingdom	Living labs and co-production: university campuses as platforms for sustainability science: Generation of living lab projects, the design of the campus as a living lab, and institutional visibility, identifying the key strengths of the living lab approach and the challenges of applying it more broadly		Evans et.al. (2015)
12	University of Cape Town	South Africa	Integrating environmental sustainability issues into the curriculum through problem-based and project-based learning: Curriculum development regarding Carbon Footprinting—into the Information Systems undergraduate curriculum, embedding Green IS theory and practice in the campus		McGibbon and Van Belle (2015)
13	Misr International University	Egypt	Going green in architectural education: An urban living lab experiment for a graduation green design studio in Saint Catherine: In an experimental design studio case, the students develop a range of skills and techniques for new adaptive and responsive climatic architecture approaches on test cell models in a living lab environment		Dabaieh et al. (2017)
14	University of Technology Sydney	Australia	Wealth from Waste Living Lab: the UTS Wealth from Waste Living Lab is an interdisciplinary design lab for third-year design students who receive practice-based learning experiences in designing ways to increase food capture rates and reduce contamination rates		UTS (n.d.)
15	University of Tasmania	Australia	Education for Sustainability Tasmania (EfSTas): EfSTas is a United Nations University Recognised Regional Centre of Expertise in Education for Sustainable Development to advance Tasmania as an interconnected and diverse sustainable island state that can adapt and respond to environmental, economic, social, and cultural challenges		Emery et al. (2020)
16	Universiti Sains Malaysia	Malaysia	The EcoHub is a previously abandoned green space preserved by Universiti Sains Malaysia as a living lab, being home to much unique flora and fauna that can hardly be found elsewhere. It aims at becoming the "nature repository" for storing information regarding the campus's ecological surroundings, and preserving exotic flora and fauna. Students, lecturers, and researchers develop research on the flora and fauna found in EcoHub and the findings can be useful to other researchers		USM (n.d)

Table 4 (continued)

Case	University	Country	Short description	Addressed SDGs	References
17	KTH Royal Institute of Technology	Sweden	KTH Live-In Lab: the platform for accelerating innovation in the built environment: KTH Live-In Lab offers a full-scale test environment ranging from buildings and installations to housing and management organizations. Research and testing can be carried out in real buildings, enabling studies on the future's resource-efficient and sustainable student housing		KTH Live-In Lab (2018)
18	Universitat Politècnica de Catalunya	Spain	LIVING LAB LOW3: Laboratory for energy efficiency, sustainable building, and renewable energies: Energy Self-sufficient Solar House (LOW3) is a Living Lab at UPC, promoting bioclimatic strategies, and renewable energy systems, and low impact construction concepts experimentation and evaluation. The equipment contains a 4.0 kWp solar photovoltaic installation, facade integrated solar thermal collectors, low energy climate system and sensors to control several parameters, such as temperature, humidity, and CO2 concentration		UPC (n.d.)
19	Maastricht University	Netherlands	Smart City Living Lab (Smarter Labs): tests and upscaling through smart mobility experiments in four cities: Bellinzona, Brussels, Graz, and Maastricht: At Maastricht University, the Smarter Labs project is coordinated by the International Centre for Integrated assessment and Sustainable development. It consists of a series of initiatives (most notably a series of focus group meetings and a web-based design tool) that engage key stakeholders in co-designing the renovation of the central station area, addressing sustainability challenges (e.g., mobility, energy) by making optimal use of innovative, smart solutions		Smarter Labs (n.d.)
20	Maastricht University	Netherlands	Living Lab in Ageing and Long-Term Care: Researchers collaborate with end-users (e.g., older persons and their families, professionals, health care directors, and policy-makers). The interdisciplinary partnership using a team science approach and the use of Linking Pins (scientific and practice-based) are important characteristics of this living lab		Verbeek et al. (2020) Maastricht University (2018)

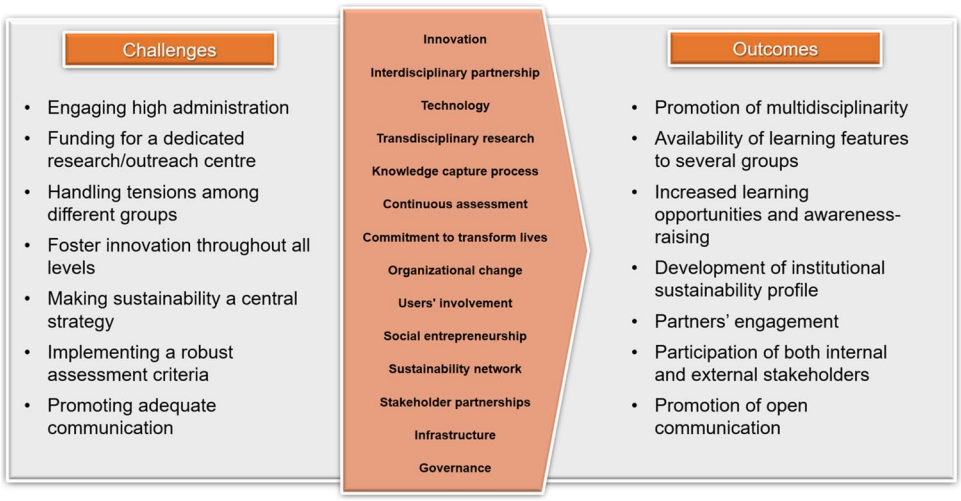

Fig. 3 Framework for action in living labs, with key features transforming challenges into outcomes

The cases of Polytechnic University of Catalonia (Masseck 2017), University of Manchester (Evans et al. 2015) and KTH Royal Institute of Technology (KTH Live-In Lab 2018) were all classified as contributors to education and resources of sustainable cities and communities (SDGs 4 and 11). The connection with these goals occurs mainly through using new learning methodologies, tools, and concepts to promote sustainable architecture, by engaging students in applied challenges and co-production, and by fostering associations with companies for enterprise-based education.

Other examples of living labs directly cover the interrelation between education and climate action (SDG 13). For example, at Harvard University (Harvard, n.d.; Purcell et al. 2019), the entire academic community is encouraged to experiment with sustainable solutions, involving innovation, climate issues, and student grants. At the University of Cape Town (McGibbon and Van Belle 2015), the curriculum supports the development of key competencies around sustainability, carbon footprint, and real-world problems. Sustainable architecture is also a highlight in the living lab of Misr International University (Dabaieh et al. 2017), by promoting educational developments and green design. A different example of a living lab is available in Europe (Smarter Labs, n.d.), from a consortium of universities with complementary knowledge distributed in four cities, i.e., Bellinzona, Brussels, Graz, and Maastricht, committed to implementing smart mobility concepts and involving not only the academic community but also companies and interested stakeholders.

Additional goals covered by the case studies sample of living labs were SDGs 3, 12, and 15. With a focus on aging and long-term care, the Maastricht Living Lab and Health Care (Maastricht University 2018; Verbeek et al. 2020) contribute to improving the quality of life for vulnerable, older people. By exploring design strategies that support waste management, the University of Technology Sydney (UTS, n.d.) contributes to the goal of sustainable consumption, especially using innovative communication tools, new bins, and events to further educate its academic community. Regarding biodiversity, the EcoHub of University Sains Malaysia (USM, n.d.) is expected to become an advanced living lab in the country, as well as one of the sustainability-based tourism spots in Penang. In addition to research that can be carried out at the hub, students support the labelling of plants so that visitors can learn about native species, thus contributing to environmental education.

Based on the above-presented cases, it can then be stated that the SDGs can only be achieved worldwide through a participatory approach from the community (Leal Filho et al. 2022c, d, e). According to Compagnucci et al. (2021), living labs can promote long-term partnerships between stakeholders, thus contributing to successful partnerships and to SDG 17 in particular (Leal Filho et al. 2022c). Living labs play an important role within HEIs relevant partnerships, as they ensure that institutions are able to engage in the sustainability agenda through different approaches, from teaching and research to industry, driving innovative solutions and enhancing collaboration between all those involved, i.e., teachers (Bürgener and Barth 2018), researchers, stakeholders and the community (Hossain et al. 2019). Engaging users is key to a successful living lab (Compagnucci et al. 2021; Hossain et al. 2019), and changing habits based on environmental concern is a strong motivational factor, particularly for the younger generation, a privileged target group (Pietrapertosa et al. 2021), as seen in the Fridays For Future movement, started in 2018. This is also relevant in the context of HEIs, where positive actions are not limited to universities and users can disseminate knowledge beyond the campus borders (Mazutti et al. 2020a, b).

As highlighted by Purcell et al. (2019), a strategic sustainability movement carried out within HEIs context may represent a major challenge for university leaders. Transformation requires time and the engagement of all while maintaining sustainability as a keystone construct for the education and management of institutional operations and decision-making. This is particularly important when considering specific SDGs, not restricted to geographical barriers, such as SDG1 or SDG13. Within the context of HEIs, living labs are part of the transformative challenge at the global level, resulting in significant changes at the organizational and societal level, due to sustainable development projects underway. It could be argued that living labs can offer universities a more central role in society, as illustrated through the case studies in Table 4, as their impacts become more visible and transversal (Burbridge 2017a, b), through flexible and adaptable sustainable development models and approaches.

Challenges and outcomes of living labs

Living labs are open, user-centered innovation ecosystems, based on a systematic approach to co-creating users, integrating research and innovation processes in real-life communities and environments (Compagnucci et al. 2021; ENoLL 2021; Fischer et al. 2021). So, living labs operate as intermediaries between citizens, research organizations, companies, cities, and regions (Leal Filho et al. 2022d) for joint value co-creation, prototyping, or validation to expand innovation, as a business (ENoLL 2021). These units offer the opportunity to re-establish meaningful connections between people and ecosystems, aiming for social-ecological restoration actions (Fischer et al. 2021).

These benefits and opportunities are not without challenges. Living labs are difficult to organise and the coordination requires additional time and resources (Steen and Van Bueren 2017b). In addition to these limitations, living lab projects might also face challenges associated with power issues between actors and end-user reluctance to engage (Hakkarainen and Hyysalo 2013). Monitoring the works is another usual challenge—to make sure valuable and inefficient approaches are identified, as well as to facilitate replication and upscaling in different settings (Van Geenhuizen 2018).

The case studies presented in Table 4 in the previous subsection are illustrative to show how it is possible to successfully implement living labs in the context of sustainable development at HEIs. However, there is a limit to what can be achieved outside the scope of HEIs. Based on the key ideas presented in Table 4 and on the literature search and bibliometric results collected, Fig. 3 presents a framework for action with important key aspects to be addressed in the implementation of living labs worldwide, beyond HEIs. The challenges experienced by living labs and the expected outcomes, particularly when applying the set of key features observed in both the literature and the case studies, are beneficial for their gradual improvement and the development of their planned activities. They can also support, directly or indirectly, the 2030 Agenda. The goal is that progress can be achieved in all aspects addressed within the 17 SDGs, fostering environmental, social, and economic development, while overcoming sustainability challenges.

Because there is some disagreement between theory and practice, it is necessary to support the need for further investment in this respect, translated in clear measurable quantification towards sustainability achievements. Operationally, an assessment tool aiming to structure the innovation process in living labs, such as the SDG-Check proposed by von Geibler et al. (2019), may be helpful. It could contribute to structuring the innovation process in the early stages of sustainability, with specific targets to address.

Conclusions and future prospects

Being considered a multidisciplinary phenomenon encompassing different domains of knowledge, the living labs concept may include partnerships among heterogeneous stakeholders and apply different tools and approaches. It is clear that a living-labs based innovation, within the context of real-world sustainability challenges, is only possible when collaboration is based on agreement and trust.

This study contributes to the discussion on the role of HEIs as promising settings in the creation of living labs that can foster the implementation of the SDGs. There are some conclusions which can be drawn from it. The first derives from the bibliometric analysis of the current academic research on articles related to living labs set-ups or contributing to the implementation of the SDGs. The results of the scientific mapping approach pointed out that keywords like "innovation", "sustainability", "cities" and "governance" have a higher occurrence in the sample of research articles used, and described the interconnections between living labs and the SDGs. More recent articles have focused on research related to "energy" and "urban living labs", as opposed to older articles that mostly discussed issues related to "technology" and "consumption". Also, the results of the bibliometric analysis stressed the multidisciplinary character of living labs in the context of sustainable development, given the variety of sources that publish articles on this subject.

The second conclusion relates to the 20 case studies of living labs organized in higher education settings, which combined and showcased successful approaches deployed to better support the achievement of the SDGs. By this token, our study offers a clear view of the impact of living labs in

institutions of higher education as an intermediary between heterogeneous stakeholders involved at the local level. Most living labs that have been analysed in this study focus on SDGs 4 and 11, which deal with providing quality education and ensuring sustainable development of cities and communities. Furthermore, the topic of climate action by means of SDG 13 is also amongst the main items that are being tackled, also fostering partnerships between stakeholders.

Thirdly, based on the bibliometric results and the case studies analysed, the paper provides important insights on aspects which need to be addressed in a future framework that fosters the development of living labs beyond higher education settings. The challenges encountered in the implementation of living labs refer to

(1) the high level of administration,
(2) the tensions between different groups of interest that need to be rendered by enhanced communication, and
(3) fostering sustainability and innovation as the main strategy of the living labs activity.

On the other end of the spectrum, the ability to create living labs that prioritise the implementation of SDGs needs to be based on premises like (1) promoting multidisciplinary approaches and open communication, (2) increasing learning opportunities for different groups, (3) focusing on developing an institutional sustainability profile, (4) engaging stakeholders from different areas of expertise.

The key features that emerged from this paper may prove to be beneficial to the success of a living lab deployment, regardless of the setting. It can also foster directly or indirectly the UN 2030 Agenda, by focusing on innovation and sustainable development. Living labs, especially those created with a focus on implementing the SDGs, could encompass various research domains from real-life environments, with the aim of transforming valuable knowledge into models, theories, and approaches. They are seen as valuable to the community in general and specific stakeholders in particular, because of the opportunities they bring through the experiments, feedback received, and high know-how spillovers that are generated in other areas of activity and that can tackle sustainable development on economic, environmental, and social grounds.

Throughout this study, it is possible to substantiate that living labs can be an effective tool for HEIs in playing an active role in the transition and transformation towards more sustainable environments. Living labs are not only a versatile tool to implement education for sustainability, contributing to the development of sustainability-related competences among students, faculty, and staff, but they can also help HEIs to transform their operational formats. This transformation would allow them to gain a more relevant role in society and in the global process of transitioning towards a more sustainable world.

Living labs are profiling as new learning trends that can facilitate the attempts of students and researchers to have a more active role in their communities, while using, experimenting and testing knowledge, as it is being produced. In this circular participation process, living labs become a vehicle for active and challenge-based learning. For these reasons, living labs should be further explored as powerful tools for an education capable of fostering the transition towards sustainable practices. In this sense, additional research is needed to identify successful factors for implementation and operationalisation of living labs that can be implemented cross-campus. At the same time, as we are moving from education *for* sustainability to education *as* sustainability, we should also start envisioning not only living labs as tools for the university, but rather the *university as a living lab*.

Future studies could focus on establishing a method to better quantify how sustainable living labs are, when compared to the tackled SDG indicators. Furthermore, the scope of this analysis could be broadened to include primary and secondary education settings, and seek the perspectives of teaching staff.

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