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Characterizing nature-based living labs from their seeds in the past

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ABSTRACT

Nature-based living labs combine the elements of nature-based solution design with a living lab context to address social and environmental resilience challenges. There is a need to deepen insights on the characteristics of the emergent phenomenon of nature-based living labs, with respect to their predecessors. Accordingly, the paper first develops an outline of how living labs evolved into nature-based living labs, informed by bibliometric analysis. Second, the unique characteristics of nature-based living labs are identified using a systematic literature review. Finally, the core characteristics of living labs are determined, and nature-based living labs are placed within this context. Initial living labs had a strong technological focus, which proliferated into diverse application domains and regions after the European Network of Living Labs was established and expanded. Urban living labs emerged as a significant multidisciplinary and geographically specific domain, while nature-based living labs are inherently sustainability-oriented and consider ecosystem processes, interactions, and natural materials. Next, the paper identifies nine characteristics of nature-based living labs, five of which are always present, namely: (i) real-life spatial context and multi-scale, (ii) innovation and learning, (iii) user-centric, (iv) multi-actor involvement and (v) sustainability-oriented multiple benefits. Then, the four core characteristics of living labs, the variation within these characteristics, and how these align with the characteristics of nature-based living labs are clarified. Finally, the need for research on living labs across application domains and regions is highlighted, so that the global applicability of these local, user-centric, innovative approaches can be established.

1. Introduction

The planet's land and water systems are undergoing continuous transformation by natural and human factors (Haddeland et al., 2014; Li et al., 2022). In recent years, the structure and functions of these systems are being altered further due to climate change (Haddeland et al., 2014; IPCC et al., 2022; van der Knaap et al., 2018). Likewise, the societal values attached to these systems that deeply engrain place-based cultures, traditions, and lifestyles are shifting under diverse future expectations (Bender, 2002). The complexities and uncertainties about the nature and extent of future changes pose challenges to the resilience of land and water systems (van der Knaap et al., 2018), both globally and locally. Therefore, landscape and waterscape management at the local and

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regional levels needs to integrate knowledge of the effects of climate change on these systems into relevant long-term strategic visions and to engage society in innovation processes for a resilient future. Such engagement of local communities to include their needs and perspectives on adaptation to climate change and their knowledge of local conditions can provide valuable inputs into policy and system planning (d'Hont and Slinger, 2022), and is potentially globally relevant for climate adaptation.

In the past, innovations that engage people were often characterized as linear processes driven and controlled by the developers (Mulvenna et al., 2011). However, open innovation via a network model that focuses on innovation activities through collaboration with external organizations has gained popularity (Busarovs, 2013; Mulvenna et al., 2011). A living lab is one such open and innovative approach that, in simple terms, involves a network of public-private-academic and other partners for real-life experimentation and innovation (ENoLL, 2022). The living lab concept received strong attention from the European Union (EU) as a step towards renewing the European innovation system by creating multi-actor cooperation models for public-private-citizen collaboration. The focus on living labs in the research and innovation (R&I) agendas of the EU led to an increase in research projects relating to living labs, for example, the water-oriented living labs by Water Europe (Water Europe & PNO, 2019; Horizon 2020 Work Programme, 2017). Research and innovation priorities at the EU level have a trickle-down effect on national research priorities (Quaglio et al., 2020). As a result, many national-level and regional-level organizations in Europe now include projects with living labs as an approach in their R&I agendas, resulting in many academics, researchers, policymakers, and practitioners active in the field of living labs. Even though existing research output is predominantly in Europe and USA, living labs are gaining increasing attention worldwide as they offer spaces where stakeholders can co-create innovative solutions to diverse problems at the interface between the environment and socio-economic development (Bouma et al., 2022; McLoughlin et al., 2018).

Nature-based solution (NBS) is one of the application domains in which living labs have emerged over the last couple of years (Lupp et al., 2021a,b). Indeed, NBS has gained ground at the core of EU R&I policy for developing a long-term, sustainable, and resilient future (Schiavon et al., 2021). According to the IUCN definition, NBSs are "actions to protect, sustainably manage, and restore nature and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature". Nature-based designs exhibit more integration and address more diverse social goals than traditional infrastructural or nature restoration projects (Slinger and Vreugdenhil, 2020) and are exceedingly used in the field of land and water management. However, NBS implementation is more efficient when supported by innovative, participatory, and collaborative approaches such as living labs (Lupp et al., 2021a,b). Therefore, the establishment of living labs that pursue NBSs (nature-based living labs) appears to represent an organic way of channeling the shifts in land and water systems toward a climate-resilient future with societal collaboration.

NBS is often used as an umbrella term for a large spectrum of ecosystem-based approaches that address societal, environmental, and economic challenges (Cohen-Shacham et al., 2016; Sowińska-Świerkosz and García, 2022). NBS approaches include natural infrastructure and ecosystem-based adaptation, such as forest landscape restoration; ecosystem-based disaster risk reduction, such as reconfiguration of rivers, estuaries, or coastal defenses; or green and blue infrastructure, such as urban parks (Cohen-Shacham et al., 2016; Sowińska-Świerkosz and García, 2022) and green stormwater infrastructure (Zhou and Wu, 2023). Similarly, living labs, too, have become an umbrella term to label a diverse set of innovation milieus (Paskaleva and Cooper, 2021) that carry out a wide variety of approaches and activities (Leminen et al., 2017; Lupp et al., 2021a,b). Emerging in such a multidisciplinary and diverse environment, the characteristics of nature-based living labs are not well-defined (Lupp et al., 2021a,b). Researchers have attempted to characterize and classify living labs previously (Ballon and Schuurman, 2015; Schuurman et al., 2013a,b; Steen and Van Bueren, 2017; Vale et al., 2018; Westerlund et al., 2018a,b). However, McLoughlin et al. (2018), (McPhee et al., 2021; Greve et al., 2021) indicate the value of research on living labs across diverse domains. Accordingly, this paper seeks to deepen insight into the emergent phenomenon of nature-based living labs. Specifically, this paper aims to (1) provide an outline of the historical development of living labs leading to nature-based living labs, (2) identify unique characteristics of nature-based living labs, and (3) determine core characteristics of living labs and place nature-based within the context.

The paper is structured as follows. Following this brief introduction, the methods adopted in reviewing the literature are described, followed by a presentation and discussion of the findings of the review. This includes a description of an evolutionary outline of living labs from their early theoretical foundations to the current development of nature-based living labs. It is followed by an analysis of the characteristics of nature-based living labs and the identification of core characteristics common to all living labs in the dataset. Finally, the last section of the paper presents the conclusions, outlining the research limitations and the scope for further research.

2. Methodology

The paper employs different methods of literature review to realize each aim separately.

Aim 1: Considering the decades of diversity in living lab literature, the paper first aims to map a rough historical timeline of the development of living labs from their initial foundation to current-day nature-based living labs. Scholarly communication and document synthesis are exceedingly important in understanding the emergence, evolution, and proliferation of disciplines (Hérubel, 1999). As this part involved tracing the development path of living labs through time, a narrative of the emergence was developed by snowballing literature proposed by Webster and Watson (2002). First, a starting set of papers on the reviews of living lab literature were considered. Then, the history and state-of-the-art living labs were traced by consulting the articles cited by or referenced in this starting literature set. The reference lists of these articles were consulted in turn until a complete narrative providing an evidence trail of the origins and evolution of living labs was obtained (Jalali and Wohlin, 2012). In total, 34 papers *(Dataset A1)* were reviewed, spanning a time period from the early 2000 to the present. These papers were selected such that they helped in creating a chronological outline of living lab emergence branching to nature-based living labs. It should be noted that this was a subjective process, unlike the systematic literature review method.

Next, a bibliometric analysis was conducted to map the living lab landscape as proposed by Van der Have and Rubalcaba (2016) and Linnenluecke et al. (2020) to support and validate the findings from the snowballing method. Author-keyword co-occurrence analysis was conducted for different timescales using VOSviewer software (Van Eck and Waltman, 2010) for a minimum repetition of 10 and 5 words. Fig. 1 informs the database of literature search, search keywords, data limitation and screening conditions, timelines developed, and total number of articles analyzed *(Dataset A2*) for each time period. The bibliometric analysis will highlight the keywords used at a certain point in time, thus quantitatively informing and validating the narrative formed.

Aim 2: The second aim of the paper, i.e., to identify unique characteristics of nature-based living labs, was achieved by conducting a systematic database literature review. A systematic literature review is adopted as the primary research strategy for this endeavor so as to collect a wide range of relevant peer-reviewed research evidence that covers the characteristics and current conceptualization of nature-based living labs as informed by Linnenluecke et al. (2020) and Munodawafa and Johl (2019). Both living labs and NBSs have emerged since the early 2000s (Cassin, 2021; Leminen et al., 2017). However, concepts similar to living labs and NBSs have existed in practice previously. Hence, to capture the concept of nature-based living labs in a comprehensive manner, keywords similar to living lab and NBS were used for the search conducted on Scopus and Web of Science (WoS) from May 2022 to July 2022. Basic information such as title, authors, publication year, name of the journal, and abstract of 141 unique papers were saved in a temporary MS Excel file. Next, the abstract of each article was read to ensure that these papers have living labs and NBSs as the main focus of the article, as shown in Fig. 1. Finally, the full text of the articles was consulted to obtain a small sample of articles (12) *(Dataset B*) that allow the characterization of nature-based living labs.

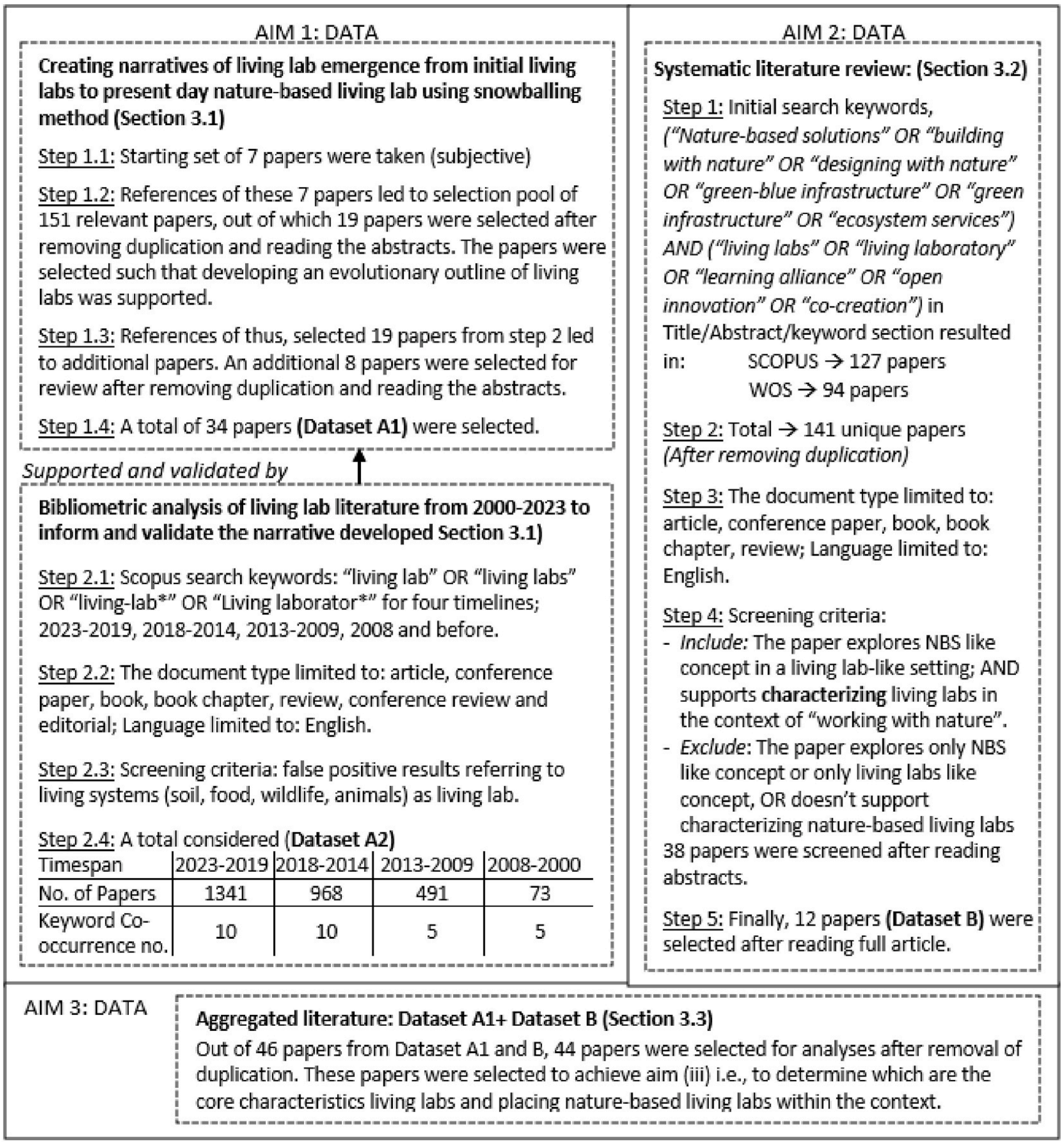

Fig. 1. Selection strategy adopted to achieve each aim in this study.

Aim 3: The third aim of the paper to determine the core characteristics of living labs and place nature-based living labs within the context, is achieved by aggregating datasets A1 and B.

A qualitative meta-synthesis on dataset A1 and a statistical analysis of dataset A2 was conducted to identify the living lab evolution pattern. Similarly, a qualitative meta-synthesis of dataset B was conducted separately to identify unique characteristics of nature-based living labs.

For dataset A1, the timeline of the historical development of living labs to the current-day and their defining characteristics were developed to address Aim (1). The starting set of papers was selected that deal with the systematic literature review, history, and meta-analysis of living labs, allowing an initial understanding of living lab emergence, diversity regarding their application domain, innovation, and types of user involvement. In each publication, attributes such as the approximate timeline of living lab establishment, geographical location, context, and characteristics were investigated. These attributes were collected and analyzed to identify the historical timeline of living lab development and their respective characteristics. As this was a subjective method, a quantitative bibliometric analysis was conducted on dataset A2 to inform the narrative. To improve the readability of the visualization in VOS-viewer, keywords such as "living lab", "living-lab", and "living labs" were all identified as "living lab". Similarly, "nature-based solution", "nature-based solutions", "nbs", and "ecosystem services" are identified as "nbs", as proposed by (Greve et al., 2021). Further, a bibliometric coupling of living lab literature based on countries was conducted to grasp the proliferation of living labs across different regions.

For dataset B, an analysis of the contents of the articles in light of Aim (2) produced a new understanding of the most important characteristics of nature-based living labs in relation to preceding living labs. In each publication, the living lab context, such as application domain, geographical area, scale, purpose, the involved actors, activities, innovation aims, the role of users, and focus on sustainability, were investigated. These attributes were then analyzed to identify the unique characteristics of nature-based living labs. A table highlighting the key findings from the selected literature is presented in the supplementary material. Finally, the aggregation of datasets A1 and B was used to understand the core characteristics common to all living labs to address Aim (3).

3. Results and discussion

This section is divided into three to shed light on each of the research Aims (1), (2), and (3), in turn. Section 3.1 seeks to establish the historical development of living labs, leading to the present-day nature-based living labs. A rough timeline of this development is depicted in Fig. 2, which is examined and validated by quantitative bibliometric analysis in Fig. 3. Section 3.2 identifies characteristics unique to nature-based living labs. Finally, section 3.3 discusses core characteristics common to living labs along with the range of variation within these characteristics and places nature-based living labs within the context.

3.1. History of living labs and the emergence of nature-based living labs

3.1.1. American smart-home technology-driven living labs

The early use of the notion of "Living Labs", used interchangeably with the term "Living Laboratory", took place in the late 1990s and is often credited to Professor William J. Mitchell and his research associates at the MediaLab and School of Architecture and City Planning, Massachusetts Institute of Technology (Dutilleul et al., 2010; Eriksson et al., 2005). Even though Mitchell is noted as a pioneer of living labs, the term "Living Lab" occurred earlier in the scholarly work of other researchers (Følstad, 2008; Leminen et al., 2017). These living labs were usually used to indicate the "in-situ" nature of research (Ballon and Schuurman, 2015). Prior to Mitchell, Bajgier et al. used the term "living labs/laboratory" to describe students' experimentation to solve problems in Philadelphia (Lupp et al., 2021a,b). Mitchell designed living labs to acquire more realistic and accurate information on the user's everyday life by observing their behavior in the usage of emerging home technologies for several days or weeks in the setting of a real home-like environment (Eriksson et al., 2005). The basic idea behind such living labs was to include users in the innovation (value-creation) of emerging technologies (Eriksson et al., 2005). These living labs were based on real-life experiments, were innovation-driven, and users were the subject of study so that the alignment of the products with user preferences could be improved.

The major difference between these living labs and the so-called "house of the future" or "homelabs" present at the time is that the focus of the living labs lay in making the innovation system user-centric while the latter stuck to being a showcase for technology (Eriksson et al., 2005; Markopoulos and Rauterberg, 2000). The technology showcase type of living lab is often referred to as the "American" notion of living labs (Schuurman et al., 2013a,b). In the 1990s, such as the Philips Homelab in the Netherlands and Fraunhofer InHaus in Germany already existed (Ballon and Schuurman, 2015). Nevertheless, Mitchell and his research team were considered influential in transferring living lab ideas from the US to the Nokia Corporation in Finland and, more widely in Europe, contributing to the rise of European living labs (Leminen et al., 2017).

3.1.2. Early European ICT-driven living labs

Living labs appeared as real-life testing and experimentation in mainstream research and innovation in private European ICT firms during the early 2000s (Følstad, 2008). One of the earliest European living labs is the "NokiaSpacelab real-life research environment", established in Finland in 2001 through the collaboration of the Nokia Corporation in Finland and Prof Mitchell's team (Leminen and Westerlund, 2019). From a commercial angle, many ICT businesses found it crucial to understand consumers in a real-life context. This led to tailoring the living lab concept to more general ICT-enabled applications, not only home technologies like the American living labs (Eriksson et al., 2005). During the same period, other living labs, such as "Vacation on Campus" at Eindhoven University, were designed as "a platform for collaborative research projects that would serve as a development and testing ground for novel technologies" with a vision of ubiquitous computing (Markopoulos and Rauterberg, 2000).

During the early 2000s, Europe wanted to prepare for the competitive global market through ICT innovation (Eriksson et al., 2005). Living labs were used to explore and innovate the quality of the user experience while using specific technologies, for example, mobile communication services. In this context, the living lab became an R&D method where ICT innovations were created and validated in real-life, user-centric, and open environments, which led to improved user-interface design, increased acceptance, and the co-design of innovations (Eriksson et al., 2005; Leminen and Westerlund, 2019). Living labs, therefore, represented a shift in innovation research, aiming to bridge the gap between technical parameters and human experience factors (De Moor et al., 2010). Designed for collaboration, these living labs focused on an open innovation environment since their initialization (Fig. 3).

The European living labs formed a fundamental re-interpretation of the American notion of living labs: users were not studied in a home-like laboratory but rather in their everyday living conditions (Ballon and Schuurman, 2015). The idea of having users as co-creators arose from the notion that innovation is not created by systems but by humans and that the interaction of market, society, and technology is needed for highly accepted and economically feasible innovations (Eriksson et al., 2005). Thus, the initial living labs in the context of commercial ICT can be characterized as focused on real-life problems, user-centric, and driven by technological innovation based on a real-life environment.

3.1.3. Establishment of the European Network of Living Labs (ENoLL)

In Europe, the living labs movement gained momentum after the European Commission launched the Helsinki Manifesto in 2006 and established the European Network of Living Labs (ENoLL), promoting the European innovation system and stressing living labs as one key solution (Dutilleul et al., 2010; Schuurman et al., 2015). ENoLL aimed to connect scattered regional ICT living labs and support the formation of new living labs in an open platform by enabling knowledge exchange, networking, and shared innovation to foster standard methods and tools across Europe (Schuurman et al., 2015). Many European Commission reports, such as the i2010 policy statement, pointed out that Europe needed to catch up in its ICT investments (Eriksson et al., 2005). Thus, the EU policy framework for information society and media (i2010) supported living labs as strategic initiatives to strengthen innovation in ICT research (Ballon and Schuurman, 2015; Schuurman et al., 2013a,b).

Until the Helsinki Manifesto, the i2010 policy, and the formation of ENoLL, most living labs were scattered initiatives from private ICT firms and were not organized as a network. Commitment from public organizations is seen as essential to support systemic innovation in Europe, where public organizations are often responsible for the overall innovation system (Eriksson et al., 2005; Niitamo et al., 2006). Hence, the EU policy measure that supported and endorsed living labs for research and innovation provided momentum to living labs in Europe. The living labs were established as broad regional development programs to test, develop, and validate innovative products and services that fulfill future needs (Ballon et al., 2005). The endorsement of living labs and the formation of ENoLL to connect these living labs were strategic efforts to accelerate innovation systems for ICT in the EU. The initial 19 living labs established in different regions of Europe and connected through the open ENoLL platform explicitly supported the pillar "Strengthening innovation and investment in ICT research" within i2010.

3.1.4. Diversification of living labs across application domains and geographical regions

Soon after ENoLL's establishment, living labs started branching into different contexts, application domains, and geographical regions. By 2010, ENoLL had become a legal entity and expanded its network outside of Europe to include members from non-European countries by establishing the Brazilian, Chinese, and African Networks of Living Labs, conducting workshops in Korea, and developing action plans in Australia and Singapore (ENoLL, 2022). Further, the World Bank and ENoLL developed a guidebook supporting living labs as a citizen-centric approach to innovation (Eskelinen et al., 2015) and recommending the living lab concept on a global scale. Eventually, living labs were established in many countries throughout the world, also independent of ENoLL's network. A bibliometric analysis of living lab literature based on countries shows that besides European countries, living labs are evident in countries like the USA, Canada, Brazil, South Africa, Japan, China, South Korea, and Mexico, to name a few (supplementary material).

The living lab approach, applied initially in technical and industrial contexts, has since expanded and developed through diverse contexts and settings (Eskelinen et al., 2015). ENoLL, while continuing to contribute to the EU digital agenda for local and regional development, branched out into several other contexts, such as innovation in public procurement, smart cities, and healthy aging (Angelini et al., 2016). Expansion of the application domains of living labs across disciplinary boundaries is a natural move where the innovation domain dealing with human and organizational issues are involved (Mirijamdotter et al., 2006), such as urban and rural planning, service innovation, health & well-being, and public services (Fuglsang et al., 2021). In addition to efforts from ENoLL, many European universities and educational institutions have adopted and adapted the living lab concept to link student creativity with the surrounding community for greater engagement and increased relevance of curricula (Eskelinen et al., 2015), leading to campus or university living labs. Similarly, many living labs (also outside ENoLL's network) have been taken up by both urban and rural communities (later coined as urban and rural living labs) to strengthen local collaboration for development and promote "territorial innovation" at a regional scale; thus, making living lab a "policy tool" to enhance local and regional well-being through multi-faceted and citizen-driven innovation (Eskelinen et al., 2015; Leminen and Westerlund, 2019). Thereupon, in addition to technological solutions and ICT innovation (Mabrouki et al., 2010; Mutanga et al., 2011), rural living labs usually focus on environment disaster prevention (Lawo et al., 2008), business models (Schaffers et al., 2007), agri-food system (McPhee et al., 2021) and so on. Likewise, future internet and ICT-enabled "smart cities" (Schaffers et al., 2011) evolved into green or eco-cities (Anthopoulos and Fitsilis, 2014) and, ultimately, into urban living labs as socio-digital innovation environments in urban areas (Molinari, 2015). These living labs were initiated by a diverse set of stakeholders, including not only private businesses or academia but also public organizations and civil society (Leminen et al., 2012).

With increasing diversity in the application domains and disciplinary knowledge fields, living labs also showed variation in the degree of user involvement. The European living labs started to adopt different forms of user involvement by building upon the European tradition of user participation, e.g., the Scandinavian tradition of user contributions to design processes (Schuurman et al., 2013a,b). Hence, the role and intensity of user involvement in living labs have varied from user consultation and participation to user collaboration and co-creation (Arnkil et al., 2010). Similarly, living labs have expanded their focus from only technological innovation to various other (tangible or intangible) innovation ecosystems, such as social innovation (Franz, 2015), ecological, and environmental innovation (Weber, 2021). While some living labs were firmly rooted in their predecessors, a large group of living labs also focused on collaboration, co-creation, and knowledge exchange with users (Schuurman, 2015). With the new focus on user-centric and user-oriented innovation, the quadruple helix innovation model that includes private and public organizations, academia, and the users came into application (Arnkil et al., 2010). This network model of innovation meant that living labs were strategically positioned at the border of local or regional administration and society, adopting hybrid organizational forms (Scholl and Kemp, 2016) to allow opportunities for physical and digital activities (Bergvall-Kåreborn et al., 2015). A bibliometric analysis of keywords co-occurrence in the living labs literature over various timescales further proves the diversity of living labs across application domains and shows their transforming characteristics (Fig. 3).

3.1.5. Urban living labs

Among many applications that have employed living lab approaches, such as health care, information technology, education, and energy efficiency, a significant development relates to their application in the "smart/digital city" and "urban context". Living labs in the urban context, known as urban living labs, developed around 2011 and have become the most prevalent type of living lab in popularity and maturity (McLoughlin et al., 2018; Westerlund et al., 2018a,b). As the scope of living labs expanded to different domains, it was inevitable that cities should receive attention, particularly as the concept of the digitalization of cities and the provision of internet access for citizens - "Digital Cities" - had already taken hold in Europe since the 1990s (Ballon and Schuurman, 2015). Furthermore, ENoLL contributed to forming a smart city portfolio, thus contributing to the foundation of the connected smart cities network (Aversano, 2016).

The initial aim was to achieve cities' development goals to become "smart or digitalized" cities (McLoughlin et al., 2018). However, the application range is not confined to digitalization (Voytenko et al., 2016). In Europe, over 70% of the population lives in urban areas such as cities, towns, and suburbs, and this is expected to increase to over 80% by mid-century (Directorate-General for Communication, 2022; Nabielek et al., 2016). With such a concentration of people from diverse backgrounds, cities are perceived as hubs of entrepreneurial and innovation activity. Urban living labs started to shape public spaces where city governments could engage citizens and steer co-design processes toward developing innovative services (Eskelinen et al., 2015; Mccormick and Hartmann, 2017). They were applied to tackle the challenges of sustainability and urban governance to achieve a broader learning experience, empower civil society, and exercise innovative forms based on actor participation (Chroneer et al., 2019; Voytenko et al., 2016). The urban living lab proliferated, moving from initial applications for smart/digital cities to applications for sustainable cities, with the emphasis shifting from users to civil society and from a narrower ICT or infrastructure focus to broader social, environmental, and governance aspects. Steen and Van Bueren (2017) present characteristics of urban living labs as innovation, co-creation, multi-participants, real-life context, and iteration. Furthermore, living labs do not have one single method but rather follow diverse methods such as observation, survey/interview, focus groups, public events, series of meetings, co-creation workshops, and so on (Huang and Thomas, 2021).

Established at the intersection of research, public innovation, and policy (with a networked or hybrid organizational form), urban living labs intend to design, demonstrate, and learn about urban innovations (Bulkeley et al., 2016). However, urban living labs deal with the urban context, which is not an application domain but a geographical locus. Various disciplinary fields co-exist within the urban landscape, leading to different understandings of what an urban living lab is supposed to achieve (Rizzo et al., 2021). In line with the EU research and innovation agenda, there has been a rise in the number of urban living labs that apply NBSs to develop resilience and increase the sustainability of urban communities (Sarabi et al., 2021), such as EU-funded Horizon-2020 projects (Chroneer et al., 2019). Urban living labs implementing NBSs are crucial in delivering environmental goals for cities with high population concentrations. However, their applications and the types of nature-based interventions they apply are relevant specifically to urban contexts, whereas there are living labs implementing NBSs in a wider geographical context.

3.1.6. Nature-based living labs

Although the population density of European cities has been increasing over the last 50 years, they occupy less than 20% of the total land area (Nabielek et al., 2016). Further, the cities are crowded with people and existing infrastructures, thus limiting possibilities for large-scale implementation of NBSs. Although effective, NBSs with their locus only in urban areas usually comprise small-scale interventions such as green roofs/facades, underground water storage, free-standing living walls, or a single-line or group of trees. However, NBSs can cover a wide array of interventions at varying scales (buildings, neighborhoods, municipal regions) and loci (cities, coasts, river basins, rural areas, forest areas, agricultural areas, or mountainous areas) (Dorst et al., 2019; Slinger et al., 2022). For example, the spatial scale of an NBS that aims to enhance biodiversity, strengthen climate adaptation, and address natural hazards is usually at a large landscape scale (Lupp et al., 2021a,b). Living labs implementing NBSs need to consider interactions at multiple scales across different geographical locations and need not be confined to the spatial scale or geographical context of the urban setting. Both living labs and NBSs must be tailor-made to be appropriate, as they are context-specific in both time and space (Cohen-Shacham et al., 2016). Thus, the living labs with a primary focus on innovation and implementation of NBS, termed nature-based living labs, are taken as a new application domain that exists across multiple scales and manifests at different loci (a few examples in Table 1).

The EU has positioned itself as a leader in "innovation with nature" (Zingraff-Hamed et al., 2020). While living labs form a part of the European Union (EU) research and innovation (R&I) agendas, NBSs support major EU policy priorities, particularly the European Green Deal, the biodiversity strategy, and the climate adaptation strategy (Directorate-General for Communication, 2022). The current policy goals of the EU regarding NBS are implemented under EU research and innovation projects such as Horizon 2020, the Bio-divERsA ERS-Net, and the upcoming Horizon Europe (Directorate-General for Communication, 2022). At the same time, efforts to promote living labs as a citizen-centric innovation approach to development are being undertaken internationally (ENoLL, 2022; Eskelinen et al., 2015).

A rough timeline summarizing the evolution of living labs through their initiation in America, their application in Europe, and their development towards the potentially globally relevant nature-based living labs is depicted in Fig. 2 and Fig. 3. Section 3.2 explores nature-based living labs in detail, deriving insights on their unique characteristics.

3.2. Defining characteristics of nature-based living labs

Nature-based living labs combine concepts of NBSs and living labs. NBSs inherently require some elements of living labs, such as real-life context, multi-actor involvement, and multiple knowledge perspectives (Slinger and Vreugdenhil, 2020), which makes them compatible with the living lab concept. Other elements of NBS that are not inherently present in the living lab concept, such as the use of natural materials and ecosystem processes in the form of design artifacts and a long-term perspective, are additional characteristics of nature-based living labs (Slinger and Vreugdenhil, 2020). Thus, nature-based living labs enable co-creation in a transdisciplinary manner that contributes to various social and environmental challenges by pursuing innovation regarding nature-based artifacts, such as integrating water and landscapes using materials, forces, and interactions present in nature (Bouma et al., 2022; Slinger and Vreugdenhil, 2020; Waterman, 2010). The transdisciplinarity of nature-based living labs lies in scientific cooperation between different disciplines and non-academic actors (Unger et al., 2022) and is supported by active collaboration between public and private sector organizations, academia, and civil society (McPhee et al., 2018). The results of transdisciplinary research enable mutual learning across the science-society interface (Jahn et al., 2012). Further, Bouma et al. (2022) suggest that a pragmatic approach focusing on collaboration between various relevant actors, such as land-users, nature conservation organizations, water boards, and researchers across different spatial scales, is needed to attain the goals articulated by the UN Sustainable Development Goals and the EU Green Deal.

The overview of living lab characteristics from various literature presented by Lupp et al. (2021a,b), and Chroneer et al. (2019) provides starting points for characterizing nature-based living labs. Nine characteristics are found to distinguish nature-based living labs, the first five of which are always present in nature-based living labs, while the last four are sometimes evident (Table 2). A summary of the literature review from which these characteristics derive is presented in Table A in the supplementary material.

Table 1
Illustrative examples of Nature-based living labs.

	Aim	Stakeholders	Location
KLIMAP	Investigates the design of climate-adaptive ways for agriculture and nature using several NBS interventions. For example, investigation on the performance of perennial grain in terms of drought tolerance, biodiversity, and feed quality.	24 parties, including regional governments, knowledge institutions, & companies & farmers (in some field-experiments)	Sandy soil landscape in Netherlands; *Example from Middelbeers*
Living Lab Grensmaas	Delivers knowledge about NBS to support large-scale interventions for flood protection, thus contributing to water system resilience. As a part of the "Room for Rivers" project, the river system is allowed more space to hold water, at the same time increasing habitats for local wildlife "rewilding" and creating recreational space for inhabitants.	Climate café as a dynamic community of stakeholders; engagement with academic, public-private, and civil society	Netherlands, along the river Maas
Living labs 1.0 by Circular Bioeconomy Alliance	Empowers nature and people by developing NBSs that enhance ecosystem services and foster sustainable livelihoods. For example, restoring forest cover using agroforestry to tackle the issues related to erratic rainfall, floods, and droughts while developing livelihoods through sustainable agriculture and land management practices.	Local communities, Local government, ARCOS foundation, Reforest'Action (knowledge company)	A global network of LLs for nature, people, & planet (Brazil, Italy, India, Columbia, etc.). *Example from Rwanda*
PHUSICOS Living lab under the EU Horizon 2020 program	Aimed at demonstrating the robustness of NBS in rural mountain landscapes. For example, reshaping the slope through wooden terrace techniques and establishing vegetation that stabilizes sediments to manage risks of erosion, rockfall, and landslides, at the same time decreasing the need for maintenance and adding aesthetic benefits.	The quadruple helix participation model (Zingraff-Hamed et al., 2020)	Norway, Italy, Spain, and France as demonstration sites. *Example from St. Elena, Spain*

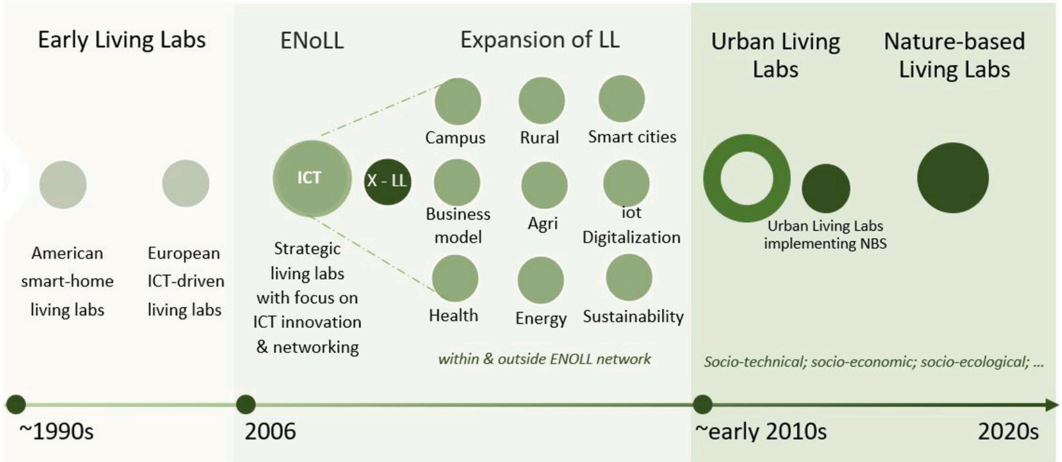

Fig. 2. A rough timeline showing the proliferation of Living Labs since their emergence leading to nature-based living labs*; where LL stands for "Living Labs"; X-LL stands for other domains of living lab application not itemized in the study; EnoLL stands for the "European Network of Living Labs".*

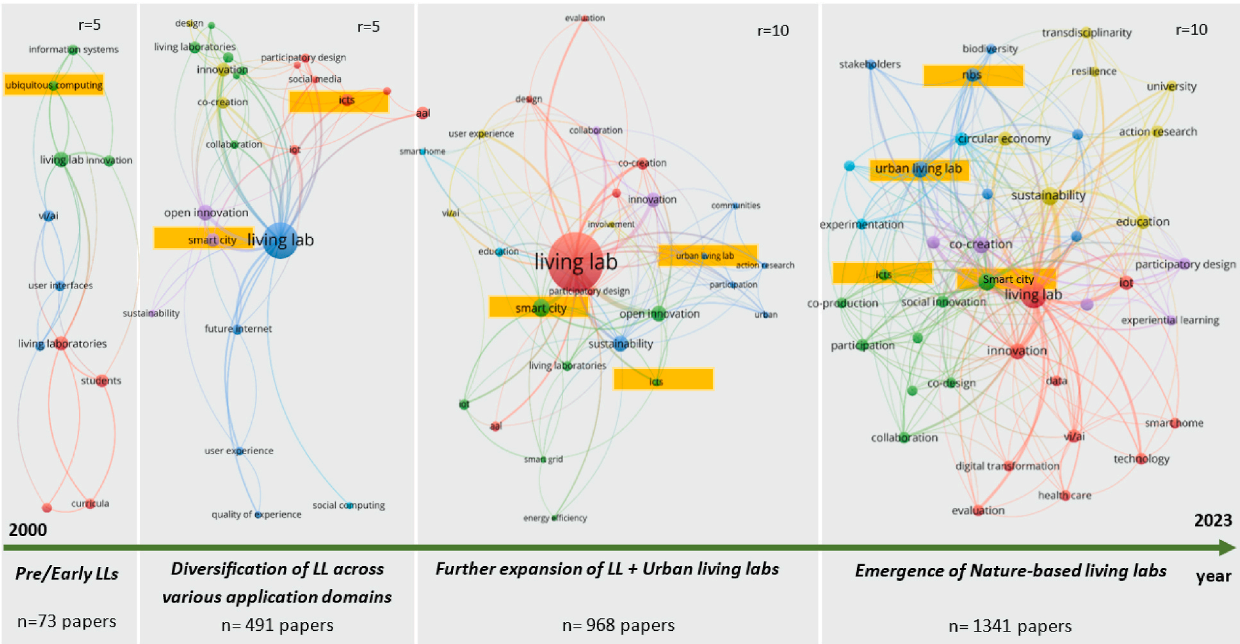

Fig. 3. Co-occurrence of keywords in the living lab literature, where highlighted keywords indicate the emergence of certain domains relevant to this paper. The left-most block shows ubiquitous computing evident in early living labs, followed by ict-driven, smart-city-related LL during ENOLL and its expansion. The Urban Living Labs appears in the second block from the right, and finally, LL applying NBS in the right-most block (at the top), *n = number of living lab literature analyzed; r = minimum number of keyword co-occurrence; Software: VOSviewer.*

1. Real-life spatial context and multi-scale

Nature-based living labs occur in real-life settings. Real-life settings are the natural surroundings or environments where living beings and specific phenomena occur and operate, distinct from artificial laboratory settings (Leminen et al., 2012). Nature-based living labs are geographically embedded in the location where NBSs will be applied, or co-creation activities with stakeholders will take place (Chroneer et al., 2019). Nevertheless, many living lab co-creation activities, such as brainstorming, interactions, and visualizations, can occur digitally (Nunes et al., 2021) or use virtual reality. However, the real-life environment means that there are many interactions relevant to the geographic location that occur at a diversity of scales. This multi-scale aspect is a universal characteristic of a nature-based living lab, as captured in the literature review. The diversity in spatial scale can range from a building to neighborhoods, cities, or regions and is often interconnected across scales (Peña et al., 2020). Additionally, the varying scales can represent a diverse ecosystem and its interactions, such as forest areas, fields, river basins, and coastal areas, thus underscoring the versatility and capacity of nature-based living labs to address various challenges.

2. Innovation and learning

One of the major characteristics of living labs is their practice-based innovation (Concilio, 2016). Innovation is the process of creating and using new ideas and concepts (O Riordan, 2013). Living labs provide a platform for exploration and experimentation that leads to the innovation of products, services, or solutions (Chroneer et al., 2019). Unlike most living labs, nature-based living labs do not focus on technological innovation through ICT and infrastructure products or services, making it particularly challenging to define their role in innovation (Chroneer et al., 2019; Rizzo et al., 2021). As nature-based living labs aim to derive solutions inspired by nature, their innovations may be viewed through a different lens - the lens of social-ecological innovation (Vreugdenhil et al., 2010). Additionally, many nature-based living labs are established for exploration, collaboration, and knowledge support, where learning is regarded as one of the outcomes. DeLosRíos-White et al. (2020) distinguish different innovation roles for the quadruple helix actors, namely: (i) civil society inclusion shifts innovation from the technical to the social sphere; (ii) academia contributes to knowledge innovation; (iii) public organizations create value for society through new strategies and policies, and finally, (iv) the private sector contributes to technological and organizational innovation.

3. User-centric

User-centric innovation approach means placing the users of the intended innovation at the heart of the collaboration network and prioritizing their feedback (Arnkil et al., 2010; Lupp et al., 2021a,b). The term “user-centric” is used as an umbrella term to include numerous ways and degrees of user involvement (see Fig. 4) (Arnkil et al., 2010; Bergvall-Kåreborn et al., 2009). Most nature-based living labs support an intensive user collaboration such that they are engaged throughout the process to achieve a high degree of user involvement through co-creation (Lupp et al., 2021a,b).

For nature-based living labs, users are usually stakeholders from the local civil society, the people most affected by the problem, and those who may benefit from the implemented solutions through value creation. However, living labs can also be designed with public authorities or private organizations as the users. Moreover, the degree of users’ inclusion and the intensity of participation differs for each living lab (Lupp et al., 2021a,b). Despite being environmentally, socially, and economically relevant, the concept of NBS is less familiar to on-the-ground stakeholders (Lupp et al., 2021a,b). Hence, a nature-based living lab needs to accommodate differences in users’ perceptions and aim to form a mutual understanding of actions for successful execution.

The literature uses different “co-” terms to characterize living labs, such as co-design, co-develop, co-produce, co-implement, and co-manage, “co-” implying collaborative work. A particular focus on the term “co-creation” can be observed, which is a user-driven approach of working together with all stakeholders from the initial phase of the project throughout the process to achieve the project goal(s) (DeLosRíos-White et al., 2020). Co-creation ensures a paradigm shift from an organizational hierarchy towards integrated management and shared responsibility, with a more networked and institutionalized bottom-up way of working (Mahmoud and Morello, 2021). Co-creation has four key phases: co-initiation, co-design, co-implementation (Sillak et al., 2021), and a fourth phase of co-evaluation (Spagnoli et al., 2019). Some nature-based living labs involve a fifth key phase, namely, co-maintenance or co-management (DeLosRíos-White et al., 2020; Mahmoud and Morello, 2021). As a living system, NBS requires long-term maintenance and management planning among the stakeholders (Seddon et al., 2020). However, the degree of user-involvement may vary for different activity phases of living labs (Zingraff-Hamed et al., 2020).

4. Multi-actor involvement

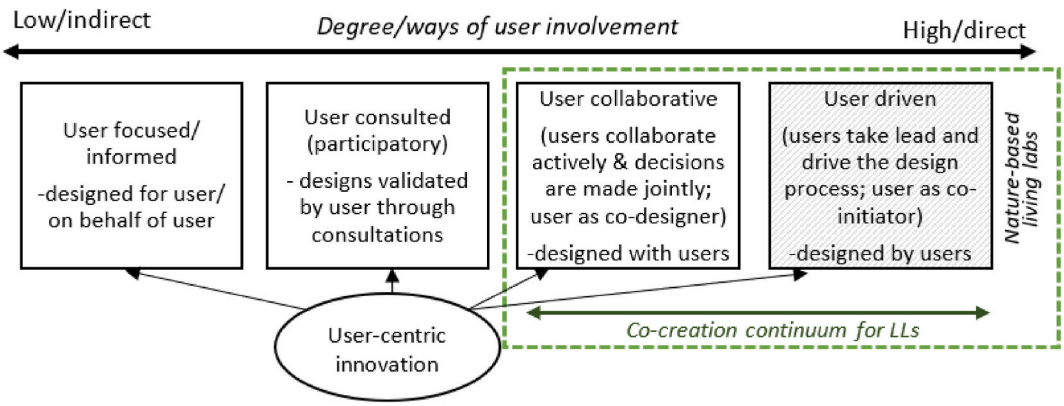

Fig. 4. Degree and ways of user involvement in innovation models; Adapted form (Arnkil et al., 2010; Bergvall-Kåreborn et al., 2009; Voorberg et al., 2015).

Living Labs require the participation of multiple actors, mostly under the quadruple helix participation model (Calzada, 2019). Developed from the tri-helix innovation system framework that focuses on the interactions of public organization, academia, and industry, the quadruple helix adds a fourth dimension as “user” or “public” (Carayannis and Campbell, 2010), and the penta helix further adds a fifth dimension as “assemblers” that include social entrepreneurs, activists, brokers, NGOs, and so on (Calzada, 2019). The actors involved in living lab activities comprise civil society (the end users of the product, service, or solution), knowledge institutes (universities, research institutes), public actors (local/regional government, public institutions), private actors (business firms and companies) and other relevant organizations. The public sector as an actor fulfills a regulatory role and potentially provides a long-term perspective, while the private sector often provides practical or business know-how and resources (Rizzo et al., 2021). Similarly, academia delivers expertise and scientific validation, while civil society is the target group and provides the behavioral definers (Rizzo et al., 2021). The actors interact and link with each other, developing collective dynamics that can lead to solutions.

Along with a focus on the multi-sectoral stakeholder network, some literature focuses on the multidisciplinary background of participants (Scholl and Kemp, 2016). This literature review reveals that nature-based living labs usually follow the quadruple helix participation model and create a cross-boundary arena or meeting space where diverse actors and organizations with multidisciplinary knowledge interact. However, Zingraff-Hamed et al. (2020) identify that “throughout the living lab process, stakeholder groups will have varying interests in different stages, providing expertise or being decisive or productive only in certain phases”. Furthermore, Alméstar et al. (2023) opted to embed the quintuple helix innovation model during their NBS co-creation process. Based on the quadruple helix model, the quintuple helix adds a fifth dimension as knowledge production in the context of the “natural environment” (Carayannis and Campbell, 2010). Apart from the human agents, the circulation of knowledge interaction to promote “sustainable development” and “social ecology” is a key element of the Quintuple helix model, which is likely a future trend in the field of nature-based living labs, given that they are inspired by nature.

5. Sustainability-oriented multiple benefits

Sustainability-oriented actions are not inherent to all living labs, but a deliberate addition (Sevaldson, 2018). However, nature-based living labs, by implementing nature-based artifacts, provide a wide range of ecosystem services that seek to move towards a sustainable future by overcoming particular environmental and social challenges. Thus, they offer a multiple-perspective approach by combining nature-centric with user-centric approach, making sustainability-oriented actions inherent to nature-based living labs. Some examples of environmental challenges that nature-based living labs tackle are climate change effects, heat stress, poor air and water quality, flash-floods and droughts, and biodiversity loss, whereas social challenges include reducing health and well-being, tackling unemployment and enhancing social cohesion, environmental justice, and citizen awareness (Arlati et al., 2021; Rizzo et al., 2021). The co-creation process in a nature-based living lab brings multi-stakeholders and their knowledge together to enhance and enable sustainable transition or transformation through NBSs. Actions aimed at sustainability are usually envisaged as providing multiple economic, social, and environmental benefits. Such multiple benefits characterize nature-based living labs and are highlighted in the literature where NBSs are implemented (Arlati et al., 2021; Clavin et al., 2021; Nunes et al., 2021; Rizzo et al., 2021), for example, parks and water bodies are designed to reduce regional heat stress, benefit the health and well-being of humans, and improve tourism. Further, the literature review indicates that additional, longer-term benefits include capacity building, practice-based knowledge production, positive behavioral changes, and possible business model development.

6. Openness and equal power

Openness in living labs is referred to as open development and innovation cooperation between living lab actors (Arnkil et al., 2010). Openness is considered one of the key characteristics of living labs (Eriksson et al., 2005; Leminen, 2015) but is not always clearly present in all nature-based living labs. However, some literature highlights challenges to openness arising from intellectual property rights as this is likely to arise as innovation progresses from experimentation to business models (Kviselius, 2009; Niitamo et al., 2006; Veeckman et al., 2013). However, most of the literature mentions little to nothing about openness. A complementary aspect of openness in living labs is the “non-hierarchical” or “equal” decision-making power between all participants and the possibility to join or discontinue association with living labs at any point. While some articles highlight the role of fixed key stakeholders (Gibson and Slovák, 2015), many provide empirical examples that indicate equal decision-making power in their living labs. However, they fail to explain the measures to ensure a non-hierarchical stance.

7. Monitor and evaluate

Monitoring activities and evaluation of living labs are not necessarily, nor thoroughly, carried out in all living labs. This is not a universal characteristic. Instead, only a few living labs extensively evaluate their process and progress. Nevertheless, monitoring and evaluating are essential to provide feedback on the effectiveness of nature-based living labs. To evaluate the initial outcomes of nature-based living labs, Lupp et al. (2021a,b) interviewed stakeholders regularly to assess their perspectives, learning processes, expectations of NBSs, and lessons learned from collaborative work. Arlati et al. (2021) and Mahmoud and Morello (2021) highlight the co-monitoring phase, which facilitates assessing the impacts of interventions on the environment of a city. Similarly, Mahmoud et al. (2021) developed a social monitoring framework to measure the social impact of NBS benefits.

8. Business development

Business development within living labs is not necessarily a universally applicable characteristic, but when present, it certainly can make living labs more successful. Developing a business model allows nature-based living labs to achieve longer-term financial success. However, only a few of the reviewed literature sources discuss the financial aspect of living labs. Mahmoud and Morello (2021) highlight the necessity for new business models to successfully implement NBSs and shed light on the financial challenges of securing long-term funds for managing and maintaining the interventions. Similarly, Lupp et al. (2021a,b) suggest that searching for economically attractive nature-based interventions is an approach to creating a business model within nature-based living labs.

9. Iteration, spin-offs, and upscaling

Although living labs effectively apply NBSs, it remains unclear how to diffuse the knowledge built through the living labs experience beyond the locational boundary (Ribeiro and Lewis, 2021) so that it can be embedded in policy implementation (Van Buuren et al., 2018). A growing number of researchers have applied the place-based dimension of innovation to emphasize the importance of local contexts for making innovation flourish (Rissola et al., 2017). Even though knowledge diffusion is at the core of many living labs, the innovations in nature-based living labs are recognized as highly context-dependent and site-specific, making replication of learning from them challenging (Sarabi et al., 2021). Most living labs lack mechanisms to iterate or translate into other socio-cultural, economic, and governance contexts, making "planning for iteration, spin-offs, and upscaling" a characteristic that cannot be found in all living labs. Nonetheless, some researchers address the challenges of iterating and upscaling living labs. In the literature review, projects such as UnaLab and Agrolab serve to highlight the diffusion of knowledge across different municipalities and cities (Chroneer et al., 2019; García-Llorente et al., 2019).

3.2.1. Role of digital technologies in nature-based living labs

The current literature on nature-based living labs sheds little light on digital and technological innovations. However, there are indications that emerging technologies can be applied to fulfill specific needs within living labs, enhancing the potential for creativity (Lupp et al., 2021a,b) and creating societal impact. Digital and technological innovation has been an important part of living labs from the outset. As living labs spread across domains, the innovations pursued have shifted from their primary technological focus to address social-ecological innovations. However, digital technologies, such as virtual reality or gaming simulations, can help stakeholders visualize or learn about implementing an NBS intervention and can assist in comparing against no-action situations (Piersaverio et al., 2019). For instance, the TUDelft Game lab undertakes many realistic simulations with a number of stakeholders using serious games (Lukosch et al., 2018). Similarly, WanderLab uses different visual scenarios that can be used to interact with stakeholders in a Living lab setting (WanderLab, 2022).

Further, incorporating "smart" technologies into NBSs can assist in real-time monitoring of the solutions, increasing their reliability and making technological innovation possible in nature-based living labs (Piersaverio et al., 2019). However, Li and Nassauer (2021) caution that smart-NBSs may change familiar landscapes in novel ways, leading to the unintended loss of pleasant, everyday experiences. Thus, while digital technologies have the potential to enhance innovation and reliability in nature-based living labs, smart-NBSs will require a holistic understanding of social, ecological, and technical interactions. This understanding can be achieved through co-creation processes that engage professionals, researchers, and locals in sharing knowledge and perceptions (Li and Nassauer, 2021).

3.3. Core characteristics of living labs and nature-based living labs

The living lab concept has been seen as "an environment, a methodology, or an approach" (Bergvall-Kåreborn et al., 2009), an "innovation network" (Leminen et al., 2012), a "physical space, platform, or interaction space" (Zingraff-Hamed et al., 2020) and/or an "organization" (Svensson et al., 2010). Living labs follow a flexible and iterative rather than a rigid linear process (Unger et al., 2022). Each living lab uses a mix of diverse methods and approaches and is designed distinctively based on its context, prerequisite, available resources, and expected outcomes (Bhatta et al., 2023). Synthesizing the material from the aggregation of datasets A1 and B

Table 2
Characteristics always/sometimes present in nature-based living labs.

		Characteristics of Nature-based Living Labs	Presence/Occurrence
Use of ecosystem processes, interactions, and natural materials	1	Real-life spatial context and multi-scale	Always present in nature-based living labs
	2	Innovation and learning outcomes	
	3	User-centric through co-creation	
	4	Multi-actor involvement from multi-sectors and multiple disciplines	
	5	Sustainability-oriented multiple benefits *through the design or implementation of NBS*	
	6	Openness and equal power	Not always reported/evident in nature-based living labs
	7	Monitor and evaluate	Sometimes present in nature-based living labs
	8	Business development	
	9	Iteration, spin-offs, and upscaling	Not always reported/evident in nature-based living labs

Table 3
Summary of the characteristics of different types of living labs ordered based on their evolution, geographical location, application domain, and typology.

Characteristics	American LL	Early European ICT-LL	ENoLL	Expansion of LL	ULL	Nature-based LL
Simplified Evolution timeline	Mid 1990s until early 2000s	Early 2000s	Mid to late 2000s	Late 2000s/early 2010s to date	Early 2010s/mid 2010s to date	Late 2010s/early 2020s to date
Geographical location	Mostly USA	Europe	Europe	Predominantly in Europe, plus expansion globally	Predominantly Europe plus expansion globally	Predominantly Europe plus expansion globally
Major Application Domain (Objective)	Smart home technology	ICT, mobile application	ICT, smart cities, healthy aging, digitalization	ICT, iot, smart cities, health, energy, students' engagement & learning, digitalization, agriculture, business model, public procurement, and so on	Diverse application fields including but not limited to smart cities, smart grid, energy, circular economy, urban food	Use of ecosystem processes, interactions, and natural materials; *Application of NBSs to address social and environmental challenges, sustainability, and the interactions between human activities and nature*
Living labs (LL) typology (Schuurman et al., 2013a,b)	Original American living labs	Living labs as an extension to testbeds	Living labs to support context-related research & co-creation	Living labs to support context-related research and co-creation, Living labs for collaboration and knowledge development and as policy instruments		
Real-life Setting	Experiment in real-life setting, physical space	Experimentation in real-life setting, physical space	Experiment in real-life setting, physical and virtual space, Organizational arrangement	Explore, experiment and/or evaluation in real-life setting, organizational arrangement, physical/virtual space	Explore, experiment and/or evaluation in real-life setting, usually hybrid organizational forms, in some cases geographical embeddedness, physical/virtual space	Explore, experiment and/or evaluation in real-life setting, geographical embeddedness, multi-scale, Hybrid organizational/governance form (García-Llorente et al., 2019)
Innovation	Smart home technology (Digital innovation)	Information and Communications Technology (ICT)	Strategic ICT and innovation in other technological sectors with a focus on local and regional innovation	Not limited to technology, but applied to many other sectors with strong innovation possibilities with a focus on local and regional development	Various application domains applied to the urban context. Focus on society (governance)/technology (digitalization)/spatial planning/sustainability/knowledge innovation	Major focus on nature and society, collaborative governance, Production of new types of products, services & processes with strong innovation possibilities, focus on multi-benefits, knowledge innovation
User-centric	User-focused i.e., users are observed & used for feedback	User-involvement, or engaged through a participatory approach	Participation, Co-creation, or co-design	Participation, Co-creation, co-implementation	Participation, co-initiation, co-creation, co-implementation	Participation, co-initiation, co-creation, co-design, co-implementation, co-maintenance
Multi-actor Involvement	Academic, private, users (consumers)	Academic, private, users (consumers)	Public, academic, private, users	Public, academic, private, users, NGOs, interest groups	Public, academic, private, users, NGOs, interest groups, civil society; transdisciplinary engagement	Public, academic, private, users, NGOs, interest group, civil society; Transdisciplinary engagement;
Sustainability			Not inherent	Not inherent	Not inherent, deliberate addition	Inherent sustainability-oriented actions

(Fig. 1), this section identifies core characteristics that unite the diverse living labs and places nature-based living labs within this context (summarized in Table 3). In addition to the core common characteristics, Table 3 highlights an outline of living lab evolution across diverse geographical locations and distinguishes the purpose of the living lab. The factors, evolution, geographical location, application domain, and Schuurman et al. (2013a,b) typology, therefore, appear in the first four rows of Table 3 and serve to specify the type of living lab being considered. Consequently, the remaining rows of Table 3 show four characteristics identified as being common to all living labs in the aggregated dataset:

1. Real-life setting: Even though the problem settings of living labs can vary in terms of their physical environment, the degree to which they are place-based and specific to a geographical location, and the scales at which they are implemented, all living labs address problems within their real-life contexts. The multiple scales relevant to the real-life problems addressed in nature-based living labs are a distinct characteristic of these living labs.
2. Pursuit of Innovation: The application domains and types of innovation may vary considerably across different living labs. Nevertheless, all living labs pursue innovation, be it social, economic, or technical, with some recent living labs explicitly pursuing learning as well.
3. User-centric: All living labs are user-centric such that users are involved throughout the innovation process. However, the degree of user-centric can vary between different living labs or at different action points of the same living lab.
4. Multi-actor involvement: Living labs have diversified from a few actors to include many actors with diverse perspectives and interests. Recent time living labs conform to the quadruple-helix participation model.

If a living lab does not have all the four characteristics enumerated above, it has a different kind of approach and is not a living lab. A user-centric and multi-actor approach that pursues innovation but doesn't have a real-life problem setting could be a laboratory-controlled trial (Mohr et al., 2022), for example. Similarly, a real-life, user-centric approach to innovation that doesn't necessarily include multiple actors could be a demonstrative field experiment (Quak et al., 2016). A real-life, user-centric, multi-actor approach without the pursuit of innovation could include capacity-building projects. Finally, a real-life, multi-actor approach to innovation that is not user-centric could be a system-centric real-world laboratory (Huning et al., 2021). A living lab framework with its core characteristics and aspects of potential variation is presented in Fig. 5. Similar to all other living labs, nature-based living labs have these four core characteristics to varying degrees but differ in that they are always sustainability-oriented with a focus on incorporating ecosystem processes, interactions, and natural materials.

4. Conclusion

The first part of the literature study sheds light on how living labs have evolved historically, while the second part identifies the characteristics of nature-based living labs. Then, four core characteristics common to all living labs are identified, and the range of

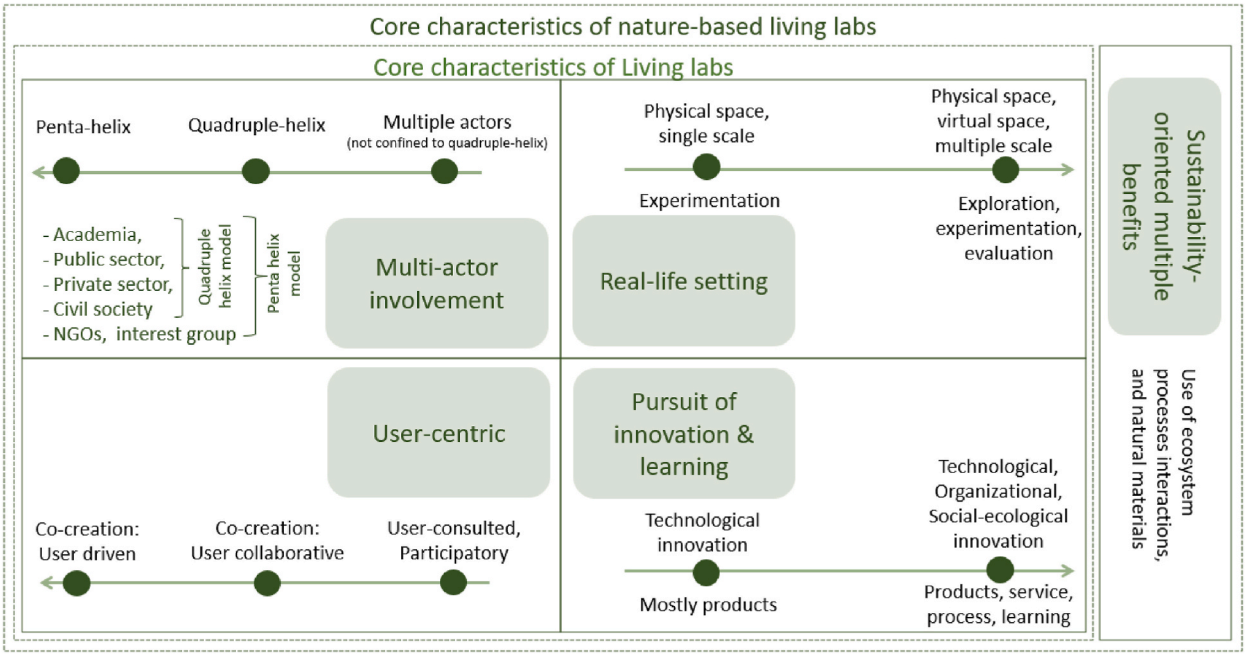

Fig. 5. Inner dotted line shows the core characteristics of living labs and the potential variation in the characteristics; outer dotted line shows the additional unique characteristic of nature-based living labs.

potential variation of these characteristics between living labs is indicated. Nature-based living labs are unique in their sustainability orientation and strong ecosystem focus.

The earliest living labs were scattered geographically, and their primary focus was to use users' experiences and feedback in innovating new ICT technologies. With the establishment of the ENoLL network, an open collaborative platform was established between various living labs within Europe. This facilitated the proliferation of living labs and their diffusion into several other domains, such as the health sector and service innovation. There was no strong theoretical foundation behind this proliferation, so living labs were used with varying intentions, such as for research, developing business (model), as a policy tool, co-creation and collaboration, citizen engagement, and learning activities. The expansion of living labs gave rise to urban living labs, which, unlike other application domains, are focused on a specific geographical context. Urban living labs made the living lab concept more familiar in diverse application areas, such as urban governance and urban climate adaptation and sustainability, thus acting as a forerunner of living labs pursuing NBSs.

Nature-based living labs specifically provide a collaborative space for stakeholders to develop innovative, environmentally driven interventions aimed at enhancing sustainability. The central defining characteristics of nature-based living labs are related to their real-life context, pursuit of innovation and learning, user-centric, the involvement of multiple actors and disciplines, and their focus on sustainability, the use of natural dynamics and natural materials, and the multiple benefits deriving from nature-based interventions. The real-life context of nature-based living labs means that they are associated with specific geographic locations in various scales, taking account of interactions at the neighborhood to the regional scale and at an individual wetland ecosystem to a river basin, for instance. In contrast to earlier living labs, nature-based living labs seem to have less scope for technological innovation as an objective per se, and a much broader and stronger pursuit of socio-economic and ecological innovation. Aiming for sustainability, they require multidisciplinary and multi-sectoral stakeholder participation, and seek to provide multiple economic, social, and environmental benefits. Further, they emphasize the user-centric approach through co-creation and co-maintenance at the interface between society, nature, and technology.

Living labs have proliferated since their initiation in the early 1990s and have broadened their application domains considerably. However, this research explored their development only through the lens of nature-based living labs, identifying characteristics common to all living labs, namely, real-life settings, pursuit of innovation, user-centric, and the involvement of multiple actors. The degree to which these characteristics vary between different living labs is considerable with nature-based living labs having place-based and multi-scale real-life settings, for instance. Similarly, nature-based living labs are inherently sustainability-oriented and give multiple benefits deriving from nature-based interventions that is not common to all living labs.

The literature review in this study was performed using Scopus and WoS in 2022. More recent relevant literature is, therefore, not included in this paper. Even though Scopus and WoS generally provide accurate and robust data along with significant extra search functionality, they have limitations in terms of their coverage outside academia (Mingers and Meyer, 2017) and are limited in their coverage of non-English language literature (van den Heuvel et al., 2021; Van der Have and Rubalcaba, 2016). Accordingly, this study may have overlooked the perspectives of policymakers and practitioners who were involved but not well-represented in peer-reviewed papers and of foreign scientists (Katzy et al., 2012). Many "lab concepts" similar to living labs, such as innovation labs and real-world laboratories, are not explored in the study. Further, this study doesn't explore the living lab concept that is being used under various regional names in different parts of the world, for example, in Columbia, where they are called Vivelab. The authors are particularly conscious of the Euro-centric view of living labs that is present in the literature and, therefore, call on researchers active in other areas of the world to supplement the understanding of living lab evolution and the characteristics of living labs presented in this research.

Living labs are currently in use as instruments for exploring local and regional responses to global challenges such as climate change and biodiversity loss. While this study has identified core characteristics common to all living labs and those specific to nature-based living labs, further research is required on how to enhance the efficacy of living labs. This study can provide a much-needed information synthesis for researchers and practitioners to help in formulating further research questions on the functioning, effectiveness, or design of nature-based living labs using database, case-study, or interview analyses. Cross-regional database analyses, expert interviews, and case studies of existing living labs, particularly nature-based living labs, could deepen insights and strengthen their contribution to climate adaptation. Moreover, cross-regional studies on the efficacy of different living lab platforms and the governance attributes that such networks can usefully adopt, would serve to strengthen living lab initiatives globally.

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Declaration of competing interest

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Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envdev.2023.100959.

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