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Review

Sustainability-oriented labs in real-world contexts: An exploratory review

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ABSTRACT

There are growing claims that meaningfully engaging with complex sustainability challenges requires change of a systemic nature. In governing transitions to sustainability, laboratories in real world contexts are growing in presence and promise. Yet, they span an array of contexts, conceptualisations and cases, making it difficult to find and relate labs across disciplines. Moreover, it is unclear how these labs vary in their approaches to sustainability, the importance of which has been voiced by the sustainability transitions community. In addressing these concerns, we adopted the broad research question: *How can sustainability-oriented labs in real-world contexts be understood?* We systematically reviewed 53 labs from disparate fields of research that broadly share a focus on sustainability. Through a mixed-methods analysis, we present three levels of results. Firstly, we provide an overview of the diversity in distribution, thematic focus and setup of labs. Secondly, we trace 7 different research communities where sustainability-oriented labs have been conceptualized (Living, Urban Living, Real-world, Evolutionary Learning, Urban Transition, Change and Transformation labs). Thirdly, we identify three key dimensions of labs, space, process and organisation, enabling a structured understanding of lab approaches towards sustainability. We then situate our results within salient transitions research areas, namely transition geographies, governance and innovation. In concluding, we point towards fruitful avenues for future research, capable of 1) unpacking lab approaches to sustainability as a dynamic normative property, and 2) providing a basis for complementary case-based comparison.

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1. Introduction

There is growing recognition that complex sustainability challenges – ranging from segregation and inequality to biodiversity and climate change – cannot be approached adequately without fundamental changes in socio-ecological and socio-technical systems (Díaz et al., 2020; United Nations, 2015; Köhler et al., 2019). In the sustainability transitions community, there are calls for deconfiguration and reconfiguration of coupled, open-ended systems (Loorbach et al., 2017).[1] Transitions of this kind are claimed to involve radical qualitative changes in the personal sphere concerning beliefs, values, worldviews and paradigms (e.g. Sharma, 2007; O'Brien and Sygna, 2013; Göpel, 2016); in social practices and ways of living (Shove, 2010), and at the macro-scale i.e. on the nature of capitalism (EEA, 2018; Göpel, 2016). Fundamental change will unarguably occur in any case, either as a response to the unsustainabilities present in a warming planet, or as a purposive shift towards new interactions between humans and nature. Agenda 2030 does however call for a fundamental transformation of "our world to the better" as paramount in fulfilling all SDGs (United Nations, 2015). In discussions around transitions and transformation, attention is extending beyond understanding historical transitions, towards processes that enable the collective exploration of desirable and sustainable futures and a deliberate facilitation in this direction (Loorbach et al., 2017; Hildén et al., 2017).

Facilitating societal change towards desirable futures is however an endeavour of significant size and complexity. Transitional processes carry with them high degrees of uncertainty, ambiguity and ambivalence, and non-linearity in cause and effect (Rotmans and Loorbach, 2009; Schot and Geels, 2008; Shove and Walker, 2007). It is argued that reflexive forms of governance allow for a more earnest engagement with these conditions in a learning-oriented manner. They include those which develop transition governance processes (Voss et al., 2006), explore plural sustainability pathways (Stirling et al., 2007), and engage with the tension between what "is and is not" and what "should be" in a future-oriented manner (Larsson and Holmberg, 2018). Reflexive forms of governance are structured around the participation and deliberation of multiple stakeholders, often guided by the need to co-produce knowledge or co-create particular innovation outputs (Loorbach et al., 2017). Despite differences in design and context, initiatives of this kind can largely be seen to question and challenge the boundaries between "knowing" and "doing" (Stirling, 2016) by openly pursuing change characterised by uncertain outcomes (Smith et al., 2005; Voss and Kemp, 2006).

Laboratories in real-world contexts have emerged in recent years as a collection of situated, multi-stakeholder approaches to transition governance (Nevens et al., 2013; Schäpke et al., 2018). Broadly speaking, they are considered to be settings for experimentation and testing of 'solutions' to sustainability challenges in collaboration with various actors (Bulkeley and Castán Broto, 2013; Evans et al., 2016). These labs regularly take the form of bounded spaces – physical sites within a geographical demarcation – and function at the fringe of existing organisational, political, social and/or institutional arrangements in society. Additionally, they include a mix of top-down, bottom-up and hybrid arrangements, framed as settings where radical alternatives can be co-produced and shaped in limited space and time (Charli-Joseph et al., 2018).

Labs in real-world contexts appear in different discourses and have been applied towards various ends. They bring an array of conceptualisations and empirical cases. This is visible in the sustainability transitions community. For example, Living Labs have been traced to the fields of user and open innovation (Hossain et al., 2019) and to the study sustainable product-service systems (Mont, 2002; Liedtke et al., 2015). In cities, labs in real-world contexts can be seen to function in governance arrangements of relevance for urban transformation (McCormick et al., 2013), including Urban Transition Labs, Real-World Laboratories and Challenge Labs (Larsson and Holmberg, 2018; Nevens et al., 2013). In the context of climate change, labs have also been positioned in debates as decarbonisation rises up the political agendas and across governance levels. Here, Evans and Karvonen (2014) state that to *"create a space apart from the norm and by bounding space, urban*

[1] In this study, an inclusive view of transition and transformation is taken. Both can be understood as processes of fundamental change within systems, with emphasis on different aspects of change based on multiple scholarly and etymological backgrounds. Different studies have attempted to differentiate these terms (Hölscher et al., 2018) whereas numerous sub-perspectives exist also (Geels, 2019; Loorbach et al., 2017; Patterson et al., 2017; Feola, 2015).

laboratories not only territorialise carbon emissions at a small, manageable scale but also inscribe a privileged space of innovation" (pg. 415).

Given the multi-concept, multi-case nature of labs in real-world contexts, we argue that the relation between multiple lab approaches and sustainability is unclear and underdeveloped. Labs express different normative commitments in research and practice. Yet, many of these commitments are tangential to sustainability, either by equating sustainability to the environmental performance or the financial longevity of lab activities (Hossain et al., 2019). Those that do express substantial commitments to sustainability are hidden within different traditions and fields. Therefore, there is insufficient oversight into the nature of labs that have an explicit orientation towards sustainability.

Existing synthesis studies have made worthwhile contributions to the discussion around labs to date. These include understanding experimentation at a discourse level (Sengers et al., 2016), policy evaluation of climate change governance experiments (Kivimaa et al., 2017), urban climate governance (Bulkeley and Castán Broto, 2013), comparative evaluation schemes (Luederitz et al., 2017) and the generation of evidence (Caniglia et al., 2017). Others have elaborated the urban living labs approach in urban governance (Voytenko et al., 2016; Bulkeley et al., 2016). Recently, Hossain et al. (2019) systematically investigated living labs, yet limited the literature base to the fields of innovation, business, engineering and computer science. Studies of this kind tend to focus on single lab approaches, analytical elements (such as experiments[2]) and fields of research. There have been attempts to employ concepts to bridge various topics or labs, such as stylised, ideal-typical characteristics to compare different lab approaches (Schäpke et al., 2018). Yet, they remain limited with regards to the scope of lab approaches as well as the breadth and depth of literature considered. Comprehensive studies that integrate insights on labs in relation to sustainability from different discourses, cases or practice, appear to be lacking.

To address the gaps above, we argue for the value of sustainability as a bridging concept, capable of generating insights that extend across the boundaries of a single discourse, case or practice. In addition, we emphasise the need to adopt an inclusive approach regarding the range of lab approaches considered relevant for study. Therefore, we want to investigate sustainability-oriented labs in a broad fashion, guided by the following research question and connected sub-questions:

1 How can sustainability-oriented labs in real-world contexts be understood?
   a. How are sustainability-oriented labs distinguishable at a sample level?
   b. Which research communities are connected to sustainability-oriented labs?
   c. How can lab practices be characterised in relation to sustainability?

To answer the above sub-questions, we adopt a systematic review method, capable of allowing both a structured collection and analysis of cases from real-world contexts. The aim of this review is therefore not to unify discussions around a singular lab type, theory or set of concepts from an evaluative perspective. Rather, we attempt to provide a structured argument for how sustainability-oriented labs have been developing and where they originate, in a way that can offer a basis for broader understanding.

[2] While labs often host experiments and can be seen as part of a broader development of experimental governance, both are separate phenomena and studies on experiments do advance understanding of labs only to limited degrees.

The remainder of this paper is structured as follows. In section 2, we outline the methodological choices made in this systematic review and reflect upon their subsequent implications. In section 3, we present three levels of results generated from the review, corresponding with the sub-questions above. Section 4 includes a discussion of results with the intention of situating this contribution within existing strands of research in sustainability transitions. In section 5, we conclude by pointing towards opportunities for relevant and complementary research.

2. Methodology

This study adopted a systematic review procedure accompanied by a mixed-methods analysis in exploring sustainability-oriented labs. The ambition was to illuminate 1) aggregated insights from this sample, 2) the multitude of conceptual labels ascribed to them and 3) lab dimensions and practices. Systematic reviews include a wide range of methods and research designs; however, they can generally be grouped based on their respective approach to collecting and/or integrating sources (Egger et al., 1995; Bryman, 2012). In particular, reviews are commonly systematic in that they are protocol-driven and stepwise in their collection of data from secondary sources, with similar emphasis placed on transparency. The expectation is then that this data can be engaged with in a variety of ways through a synthesis process, where the nature and function of synthesis can differ significantly (Dixon-Woods et al., 2005).

A schematic of the review protocol adopted in this study is provided below in Fig. 1. The central purpose of this protocol was to systematically identify, refine and organise a collection of studies on labs suitable for the research scope of this study. We adopted a stepwise approach that incorporated the following stages: 1) data collection, 2) abstract screening and 3) full paper review. These stages correspond with the common distinctions in review processes of finding, appraising and synthesising that are identified by Dixon-Woods et al. (2006). At each stage, a series of choices were made to continuously refine and prepare the sample of labs for full paper review. Below, we outline these choices in more detail for each stage, before reflecting upon the implications of these choices from a methodological perspective.

2.1. Data collection

This review collected peer-reviewed articles as its central data source. This was done to ensure that reporting of case material and results has been subject to external review. An initial selection of articles was first identified through the development of a search string, consisting of a combination of identifying keywords (Dixon-Woods et al., 2006). We took a particularly broad and inclusive view of a lab in the choice of keywords, with the recognition that there are significant differences in the ways that this phenomenon is conceived and labelled. This breadth is illustrated through common reference to labs that carry distinguishing terms such as living, real-world, urban, transition and transformation. Our choice corresponds with the aim of this study to consciously extend understandings of labs, through the adoption of sustainability as an anchoring concept. Therefore, the key word "sustainab*" was searched in combination with a variety of lab terms, including but not limited to ""living lab*", "social lab*", "urban living lab*", "transition arena*", "sustainability transition lab*", "policy lab*", "innovation lab*", "learning lab*", "city lab*". In order to avoid the risk of an unmanageably large sample of clinical lab settings, research infrastructures and medical studies, the decision was made to use additional keywords. These "AND NOT" keywords include "clinic", "animal", "labour", and "labor". The complete

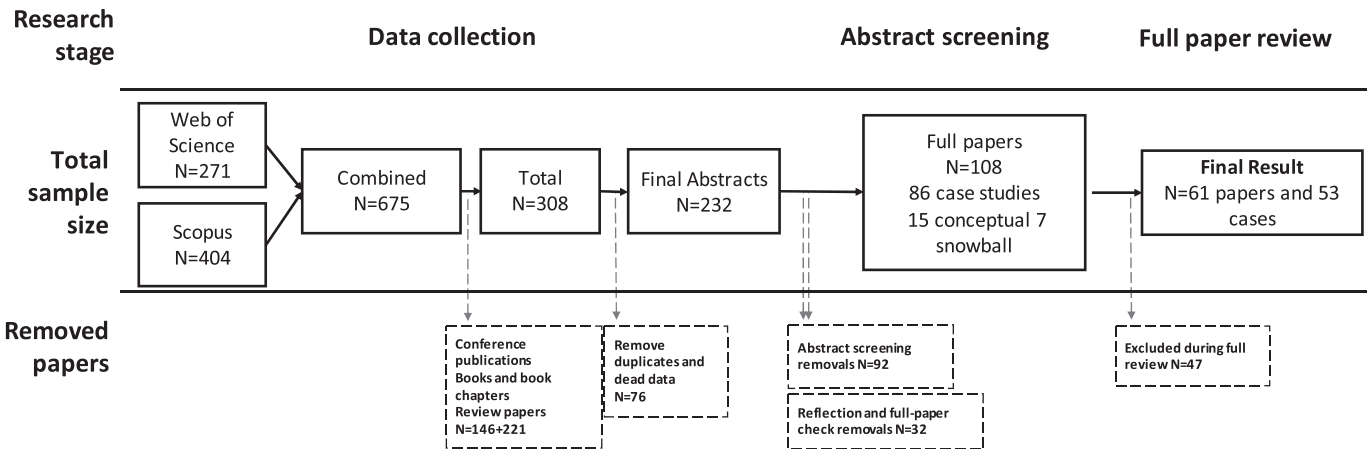

Fig. 1. Schematic of systematic review protocol.

Table 1
Exclusion criteria for abstract screening process.

Related to empirical focus of study (Labs in real-world context)	**Exclusion criterion 1** This abstract refers to labs in a manner disconnected to this research (e.g. clinical lab testing, digital testing, labs in a metaphorical sense)	**Exclusion criterion 2** In this abstract the need for labs represents a general background motivation for the study framing rather than a focus of the study itself
Related to analytical focus of study (Sustainability-orientation)	**Exclusion criterion 3** This abstract refers to sustainability in a manner disconnected to this research (e.g. longevity, sustainability as solely economic productivity or "long-lasting")	**Exclusion criterion 4** In this abstract the interest in sustainability represents a general background motivation for the study framing rather than a focus of the study itself

search string is presented in Appendix B. We used two scientific databases to collect articles: Scopus and Web of Science (WoS). A temporal scope of 1994 to 2018 was set. Conference papers, editorials and proceedings were excluded from the search so as to reduce the amount of hits not subject to peer-review processes. Additionally, books were removed from the search for accessibility reasons, apart from two: Marvin et al. (2018) and Keyson et al. (2017)).[3] Finally, both papers and metadata were downloaded as CSV files. Both CSV files were merged and organized in spreadsheets in Microsoft excel. Duplicated papers and incorrect data were deleted, and this format was supplemented manually with metadata from book chapters. Abstracts for each paper were incorporated into these sheets for subsequent stages of the review process. This initial process produced a provisional sample of 232 papers.

2.2. Abstract screening

Abstracts from all papers (N = 232) were divided between reviewers and screened to determine those to be included into further stages of the review. This screening was guided by exclusion criteria related to engagement with labs and sustainability (see Table 1). These criteria were applied in order to maintain a methodological scope for labs consistent with both our empirical focus (i.e. labs in real world settings as objects of study) and analytical focus (a clear motivation of these labs in the context of sustainability).

As the abstract screening process is generally considered a critical step during review processes, emphasis was placed on fostering a shared understanding of the screening process to reduce bias. The reviewers tested a sample of 10 abstracts and reflected collectively over the relevance of the criteria and challenges/uncertainties related to meaning and interpretation of concepts of the abstracts screened. During the full screening process, in the event that a reviewer was unable to include/exclude based on an abstract, a second reviewer would verify this abstract based on criteria. In the event that both reviews were inconclusive, both would screen the full paper for relevance, applying the same exclusion criteria. Additional periodic meetings were scheduled for reviewers to share general impressions of cases and incorporate processes of reflection during data collection. 65 abstracts were marked as "check", requiring a second review: 29 of those were then accepted (14 after 2nd screen and 15 after full paper screen). In total, 108 papers were included for a full paper review.

2.3. Full paper review

An inductive case survey method was adopted in order to facilitate the structured collection of data from multiple qualitative cases, as well as to derive insights that are exploratory in nature and extend beyond those of a single-case approach (Newig and Fritsch, 2009). In such an approach, multiple empirical cases can be represented in one paper, and one empirical case can appear across multiple papers. This study collected qualitative data on sustainability-oriented labs from the papers by creating broad analytical categories. This process was primary inductive in the sense that categories for data collection and description emerged in an iterative manner from the cases themselves. The categories sought to capture information on discourses surrounding sustainability-oriented labs, as well as general descriptive data suitable for aggregative findings. Categories were further operationalised into a total of 25 variables (see Table 2), which were then tabulated for data collection.

[3] This decision was made to ensure the inclusion of empirically rich cases specific to Living Labs and Urban Living Labs, two connected types of labs commonly framed in sustainability transitions research.

Table 2
Analytical categories adopted in full paper review of labs.

Categories	Category description	Sub-categories
Discourse categories	Description of the discourse(s) associated with specific lab cases	Research tradition within which lab is framed Definition/description of lab concept Anticipated results from paper on case Location of first author (University and country) Theory of change
Descriptive information	Generally identifiable information associated with lab case	Country of lab Scale of lab Duration of lab Current status of lab
Defining features	Specific information that generates a deeper understanding of lab case	Description of specific lab Thematic and topical focus General orientation of approach Location and character of location Nature of experimentation in the lab
Type of partnership	An overview of the collaborative arrangements that exist in lab case	Actors involved in Lab initiation Nature of collaboration within lab Involved actors in lab activities Target actors in lab to be reached Involvement of researchers in Lab Nature of funding
Normative orientation	Describes the way each lab case is orientated around sustainability	Aim/purpose of lab Sustainability challenge addressed by the lab Approach towards sustainability Approach towards scaling and transfer

Papers were divided amongst reviewers for a full analysis. Several steps were taken during the analysis process to reduce bias of reviewers and ensure a sample of labs that are within the scope of this paper. For example, all papers (including those excluded) were discussed amongst core reviewers in a series of reflections sessions during the analysis stage. As a result of this testing process, the decision was made to include an additional inclusion/exclusion round. Papers were excluded due to 1) a lack of information on several core categories of interest (lab, sustainability), 2) over-promising abstracts[4], 3) an unclear or absent methodology (lacking methods section, lacking references), or 4) other reasons (accessibility, absence of a case). In total, 47 papers were excluded during the analysis process. This resulted in a total of 61 papers, ultimately translating into 53 sustainability-oriented labs (cases) for analysis.

2.4. Methodological reflections

Here, we reflect methodologically on two different levels. Firstly, we explicate choices made in establishing a scope for this review. Secondly, we reflect upon the salience of an exploratory review approach, especially in the context of current criticisms of systematising in research.

The aim of this paper is to collect and explore sustainability-oriented labs in real world contexts. In order to prevent an ever-expanding set of partially overlapping terms, the scope was set at labs, arenas[5] and sustainability. Nevertheless, we recognise and acknowledge the various timely contributions from scholars in the research of innovation spaces (Westley et al., 2011), testbeds and demonstration platforms (Hodson and Marvin, 2009) and sustainability experiments (Sengers et al., 2016). Although these appear in socio-technical and socio-ecological systems research – and could be argued of relevance to different degrees for sustainability transitions research – this study avoided their use in developing a search string.

Two common criticisms are levelled towards systematic reviews, and in particular those with more aggregative and positivist setups. Firstly, it *"privileges research evidence over evidence from other sources, including those arising from the experience of practitioners"* (Hammersley, 2001, pg. 550). Secondly, it selectively reduces case-based insights through a unified design goal of finding "what works". Interpreted in this way, there is a valid risk that complex phenomena under study can become empirically detached from context. Methodologically, the review approach experienced a "qualitative turn" of sorts, with a growing interest in engaging with qualitative synthesis techniques in different ways (Dixon-Woods et al., 2005). In the transition community, such review examples include the work of Caniglia et al. (2017) in categorising experiments according to their degrees of control and problem/solution orientation and; the work of Torrens et al. (2019) in critically synthesising the conditional dynamics of urban settings and experimentation. In the case of our review, we adopted an approach that could incorporate contextual factors by maintaining a case focus. We began with an aggregative oversight of an existing but varied corpus of research on sustainability-oriented labs, before zooming in on initiatives in order to explore qualitative insights at the level of discourse and practice. In addition, the pronounced focus on co-creation in the sample of labs allows for the inclusion of practitioner experience through the initial studies. The particular extent to which integrative processes of this kind truly lead to integrated societal outcomes remains a topic of interest in research on transitions and transformations (Feola, 2015). Although, outside the scope of this review, we return to this point when discussing our results in section 4.3.2.

3. Results

This review generated results at three different levels, corresponding to the outlined sub-research questions. In 3.1 we provide a descriptive overview of sustainability-oriented labs at a sample level. In 3.2 we trace the research communities associated with these labs. In 3.3 we discern key dimensions from existing lab practices.

[4] In the case of overpromising abstracts, we refer to papers which appear to foreground labs and sustainability in their abstract but based on the full text analysis conduct research that constitute grounds for exclusion based on Table 1.

[5] Given the presence of arenas in Urban Transition Labs, the decision was made to include "Arenas" in the search string to ensure relevant entries in the initial search sample.

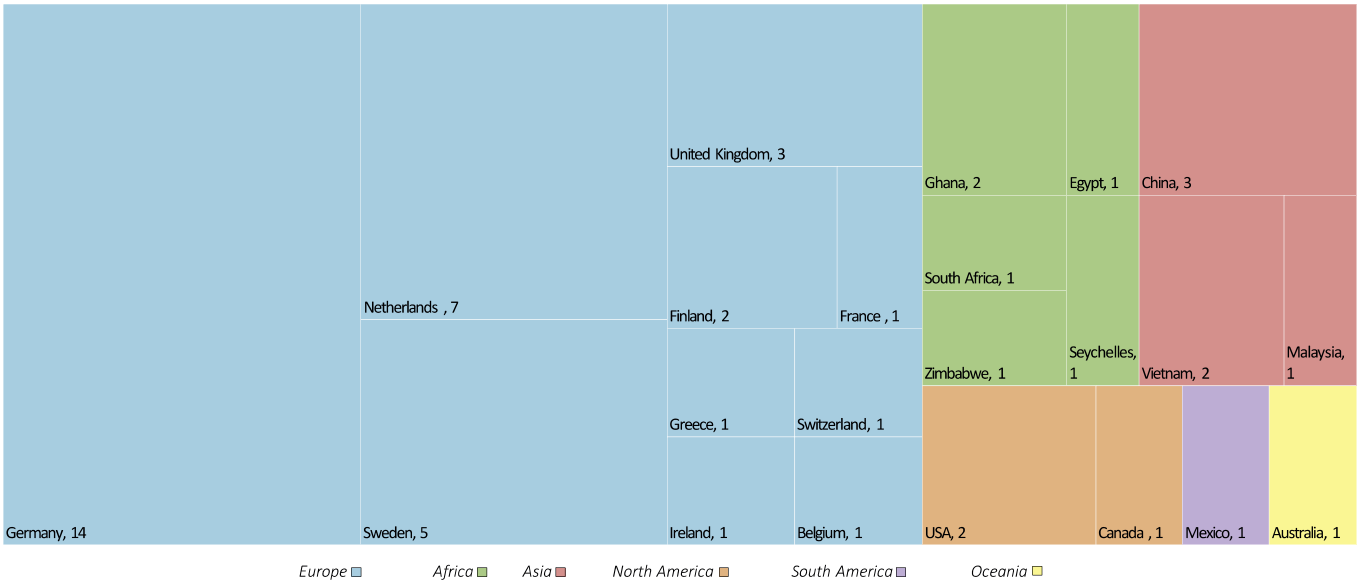

Fig. 2. Geographical distribution of labs. Hierarchy visualisation presenting the distribution of labs (N = 53) based on national (inner vector) and continental focus (in legend). Colours denote countries from the same continent.

3.1. Sustainability-oriented labs: sample overview

The results of this section include the 1) distribution of labs based on their national and continental focus, 2) thematic or topic scope, 3) geographical and physical distribution, 4) current status and funding. A total of 53 sustainability-oriented labs were identified (for overview of labs and accompanying descriptions, see Appendix 1). Fig. 2 presents the distribution of labs based on national and continental focus.

Labs were distributed across 22 different countries, situated across six continents. Despite the diversity suggested by this finding, 36 labs (68%) of all labs are situated in Europe, with 26 of those (49% of sample) from either Germany, Netherlands or Sweden respectively. A total of three labs were identified from USA and Canada. Outside of European and North American settings, 14 (26%) different labs from Asia, Latin America and Africa were identified. Thematically (Fig. 3), these labs were associated with the built environment (17%), energy-related (17%) topics, urban development approaches (17%) and participation (13%). They include net-positive buildings (Coleman and Robinson, 2018), urban climate neutrality projects (Nevens and Roorda, 2014) and social cohesion initiatives (Menny et al., 2018). Participation as a thematic focus includes participatory urban planning, do-it-yourself and adaptive governance approaches. Additional labs were focused on low-carbon lifestyles, agriculture, mobility, waste, food, health. Three labs were associated with education as a thematic focus.

Fig. 4 highlights the number of labs that occur at certain geographic levels and locations. Here, levels relate to the stated ambitions of labs across the geographical scale.

These results indicate that a variety of relations exist in how labs are situated, and the geographical scales that they are expected to operate on. Geographically, over half of all labs (34) held ambitions at the local level, with the remainder of labs connecting to the municipal (10), regional (8) or transnational level (1). Across these levels, labs manifest themselves in a variety of different places and spaces. Regarding physical locations, 15 (28%) labs were physically located in or within buildings/units, the same proportion as those located in either neighbourhoods or districts. Additionally, this review identified 14 (26%) labs with no clear bounded physical location. They build on either workshops, seminars or particular processes, but do not hold explicit geographical ambitions. Several additional observations are worth noting in the context of this sample. Just over 10% of all labs were located at the University campus level (6). These were typically described either as experimental testing facilities or buildings, multi-stakeholder initiatives within a university or as new types of curriculum and teaching for students. Three labs were identified as being physically located in cities, but with ambitions related to different geographical levels: T-City Friedrichshafen aiming to impact the local level (Lee et al., 2011), Nexthamburg the municipal level (Menny et al., 2018) and Canton Basel-Stadt ULL the regional level (Trencher et al., 2018).

This review found that labs vary in their size, current status and duration of funding. 22 labs (42%) are still listed as ongoing, whereas 28 have officially finished. Since 2008 onwards, there has been a noticeable increase in labs with an explicit orientation towards sustainability (37/53 labs began from 2008 onwards). When considering the duration of funding, this review found that a majority of labs in this sample (46) are funded (either directly, or through a larger project) for 2 years or more. Of these labs, 18/46 (39%) are stated as having extended funding for in excess of 5 years, with some notable examples of 10 year labs existing (Puerari et al., 2018; Burbridge et al., 2017; Trencher et al., 2018; Andersson and Rahe, 2017). From this sample, 7 labs had funding that was either not stated in the papers or for shorter than 2 years. In summary, we found that labs tend not to be single-event or single-year interventions. This finding differs from evidence experiments as short-term or temporary spaces (Kivimaa et al., 2017). Rather, sustainability-oriented labs here comprise a mix of initiatives that extend across multiple years and change their intervention focus.

3.2. Conceptualising sustainability-oriented labs

This section outlines the different research communities that have been engaged in theorising around labs. It is the outcome of tracing the prominent references, research paradigms, and dominant “disciplines” from which the labs in this review draw from. In

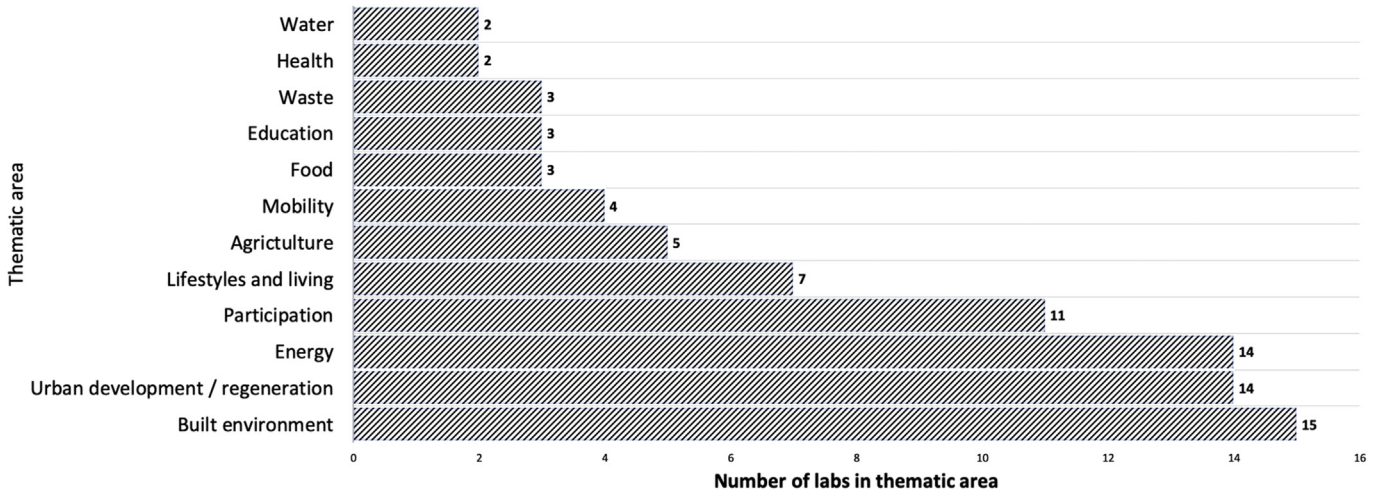

Fig. 3. Thematic focus of labs. Bar Chart highlighting the number of labs with a particular thematic focus (highest to lowest from left to right).

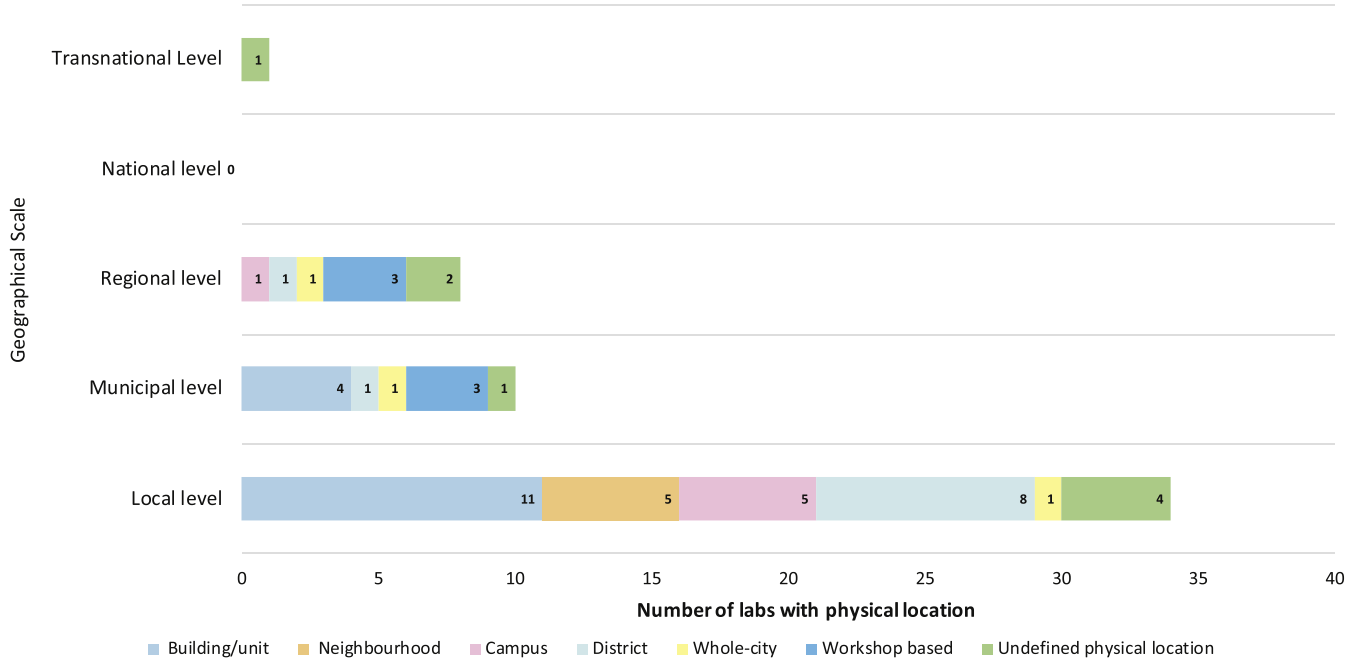

Fig. 4. Number of labs at various geographical levels and locations (N = 53). Displayed on the Y axis of the bar chart are the particular levels on the geographical scale, ranging from local to transnational. The Y axis denotes the frequency of physical properties of labs corresponding to each level, ranging from building/unit to undefined (as shown in the legend).

tracing theories of change, we identified and described central lab concepts. We grouped papers where concept definitions were shared. We then distilled and compared central analytical elements from shared definitions. Finally, we traced backwards in the literature, identifying the literary roots of definitions present in lab studies. Table 3 delineates the various conceptual labels that sustainability-oriented labs are ascribed to.

3.2.1. Lab conceptualisations within sustainability transitions

We associated lab contributions with the sustainability transitions field if key concepts are related to socio-technical systems, the multi-level-perspective or transition governance. Roughly half of all labs are either framed as **Living Labs** (16/53) or **Urban Living Labs** (11/53). The Living Lab term and approach was introduced in the 1990's and was historically focused on the commercialisation of products and services in an inclusive innovation environment. Over time it incorporated ideas from participatory design paradigms and user adoption studies, recasting the user as a prosumer and shaper of technical artefacts (Schuurman et al., 2015). As a result, understandings of more traditional and commercially Living Labs (Ballon and Schuurman, 2015) have been complemented by a more recent co-creative, integrated and practice-based methodology. Interestingly, technological artefacts remain foregrounded as an expected output of innovation. Urban Living Labs represent an emerging and connected contribution, marrying concepts from urban experimentation literature (Evans and Karvonen, 2011; Bulkeley et al., 2016) with those from user-innovation studies (Liedtke et al., 2012). The emphasis on user-centricity predominantly draws upon existing definitions of Living Labs as an arena and approach wherein real-life innovation processes can be

Table 3
Conceptual delineation of sustainability-oriented labs.

Lab concept	Description	Central Analytical constructs	Exemplary literary roots
Urban Living Lab	Governance instrument with a focus on the urban; prioritises geographical embeddedness, experimentation and learning, participation and user involvement, leadership and ownership, and evaluation and refinement	Co-creation Governance Experimentation	Evans and Karvonen (2011); Liedtke et al. (2012); Bulkeley and Castán Broto (2013); Sengers et al. (2016); Voytenko et al. (2016)
Living Lab	A pragmatic, user-centred innovation approach and environment; innovation and design process; co-creation of tech; products, services and ways of living, technology lifecycle	User needs Co-creation Usability Value User innovation	Eriksson et al. (2005): Følstad (2008); Liedtke et al. (2012); Ballon and Schuurman (2015); Voytenko et al. (2016)
Real-World Lab	Transformative transdisciplinary research approach; real-world problems and contexts; intervention object and study subject; co-design, co-production and co-evaluation	Transdisciplinarity Co-production Learning Experimentation	Lang et al. (2012); Schneidewind (2014); De Flander et al. (2014)
Evolutionary Learning Lab	A systems-based approach to understand and respond to complex issues; process as well as a setting; test mental models	Systems thinking Mental models Complexity Leverage points	Freeman (2010); Bosch et al. (2013)
Urban Transition Lab/Transition Management	Transition governance by experimentation. Deliberate process towards the governance of systemic change, including visioning, agenda setting, experimentation and learning	Experimentation Complexity Selective participation Governance Power	Loorbach (2007); Nevens et al. (2013)
Change Laboratory	Seeking transformation of cultural activity systems. A place and a process, including problem analysis and solution development in contexts	Expansive learning Double Stimuli Contradictions	Engeström (1987, 2001); Engeström et al. (1996)
Transformation Lab (T-Lab)	Interactive, participatory innovation spaces that allow for experimentation with new social-ecological technological system configurations and sustainability pathways	Resilience Adaptation Agency	Olsson et al. (2014); Westley et al. (2011)
Other	Experimental spaces, urban planning processes, learning environments	Non-overlapping constructs	Unidentified roots

nurtured (Følstad, 2008). Additionally, Urban Living Labs attempt to incorporate more explicit foci on the governance of sustainability challenges. The empirical cases used in the development of Urban Living Labs also predominantly involve European multi-city Living Lab projects (Voytenko et al., 2016) and Living Labs from the European Network of Living Labs (ENoLL), with a specific focus on urban and environmental applications.

Transition Management is viewed as a deliberate, interventionist approach to reflexive governance in times of uncertainty. Transitions management incorporates concepts from sociological theory, complexity thinking and governance theory (Loorbach, 2007), providing a conceptually grounded and empirically informed approach to exploring change in unsustainable systems. **Urban Transition Labs** (Nevens and Roorda, 2014) represent a particular way to frame transition management in cities as institutional sites for transformation, interpreted in local contexts. It could also be argued that Urban Transition Labs attempt to bridge the product and service-oriented framing of Living Labs with the transition governance perspective of Transition Management, by recasting the point of departure from the needs of a user (Schuurman et al., 2015) to a complex urban challenge (Nevens et al., 2013). This leads to a departure from the Living Lab cycle of exploration, ideation and evaluation to 1) setting the stage, 2) problem structuring and envisioning, 3) exploring pathways and building an agenda, 4) experimenting and implementing, 5) monitoring and evaluation.

Real-World Laboratories represent a spatially discrete and relatively recent conceptual development (Schneidewind, 2014), appearing mostly in a German context until this point (Schäpke et al., 2018). They are claimed to be transformative research approaches, involving *"scientifically designed spaces of collaborative sustainability research involving intervention"* (WBGU, 2016, pg. 512). Given the youth of Real-World Laboratories, research efforts are attempting to engage in Real-World Laboratory practice and generate formalised concepts and language simultaneously (Singer-Brodowski et al., 2018; Wanner et al., 2018). Similar to other lab concepts, they constitute a form of experimentation outside of clinical laboratory environments. In addition to transition scholarship (see e.g. Schneidewind, 2014), this approach draws heavily from transdisciplinarity and sustainability science in framing an approach that co-produces two interlinked strands of knowledge of relevance to both society and science (Lang et al., 2012).

3.2.2. Lab conceptualisations outside of sustainability transitions

Three conceptualisations of sustainability-oriented labs emerged from outside a sustainability transitions framing: Evolutionary Learning Labs, Change Laboratories and Transformation labs.

Evolutionary Learning Labs draw heavily from systems thinking (Maani and Cavana, 2007). It is defined as *"a generic framework and process to address any complex issue, regardless of its nature, through the creation of a platform for continuous learning and taking actions that is systemically determined — a systems-based form of 'learning by doing' by all involved"* (Nguyen et al., 2014, pg. 628). Evolutionary Learning Labs are inspired by systemic interventionism (Midgley, 2000) in employing systems-oriented methodologies to approach complex societal challenges. As such, they advocate understanding system dynamics and identifying leverage points in collaboration with multiple stakeholders. Evolutionary Learning Labs also recognise the existence of multiple mental models when approaching such systems. This epistemological stance is prominent in soft systems thinking, where emphasis shifts from ontological systems towards constructs that require systemic inquiry. This is also referred to as the movement towards "thinking in systems" (Scholes and Checkland, 1990).

Change Laboratory is a theoretically rigorous and empirically grounded intervention method rooted in cultural-historical activity theory (CHAT). It involves attempting to transform collective activity systems through expansive learning cycles (Engeström, 1987). Here, learning by expanding and "learning what is not yet there" occurs through the construction and resolution of contradictions that appear in existing organisational practices. Participants are introduced to and included in a reconceptualisation of the activity to be transformed. Examples of change laboratories can be found in the areas of healthcare, work and management contexts (Engeström et al., 1996). Furthermore, this form of intervention has recently linked to sustainability transformations,[6] supported by calls from authors for a 4th Generation CHAT that is connected theoretically to more complex systems and societal challenges (Mukute et al., 2018).

Transformation Laboratories (T-labs) represent a form of participatory space emerging from within sustainability transformations and socio-ecological systems (SES) research. They are defined *"as a means through which to provide interactive, participatory innovation spaces that allow for experimentation with new social-ecological-technological system configurations and sustainability pathways combines ideas from adaptive forms of resource management, with a growing recognition of the wicked nature of such systems"* (Charli-Joseph et al., 2018). Conceptually, T-labs draw from SES literature on transformative agency (Westley et al., 2013), resilience theory (Olsson et al., 2014) and adaptive governance (Folke et al., 2005) and are oriented towards theories of transformation (O'Brien and Sygna, 2013). Additionally, they attempt to link the prescriptive focus of transition management to an SES framing. T-labs aim to address a complex problem through the construction of collectively owned safe spaces in contexts where processes of change are ongoing. They also do so by foregrounding conditions of equity and justice in process development.

3.2.3. No clear conceptualisations

Several lab cases were not connected to an existing lab conceptualisation. These comprise experimental spaces such as Sewing Café Dietenhiem (Hector, 2018), urban planning processes such as the Berlin-Tegel case (Bahu et al., 2015), and learning environments such as those at Wisconsin University (Lindstrom et al., 2015).

3.3. Understanding practices of sustainability-oriented labs – key dimensions

Building upon the sample overview of lab distribution at the continental, national and local level as well as an outline of prominent research communities, this section zooms in on *lab practices*. It brings together dimensions that allow for a characterisation of such practices. This is achieved by iteratively distilling shared aspects from the aims, actors and activities of labs, resulting in three central dimensions of space, process and organisation (Fig. 5). Lab practices develop not only through three interrelated dimensions, but also as a product of how sustainability is engaged with as a dynamic normative property.

3.3.1. Space

Sustainability-oriented labs can be seen to display numerous spatial properties. In particular, labs here are often positioned as existing in particular places (they take place *somewhere*). Prevailing understandings of labs in sustainability transitions often describe them as bounded sites within which experimentation occurs. Here, "bounded" conjures up images of geographical demarcations with clear material properties where activities take place (e.g. a room, buildings and street). The language of sites is derived from more traditional modes of science, where the laboratory is portrayed as a specialised setting, external from society, where knowledge about a phenomenon could be produced (Latour, 1983; Livingstone, 2010). Furthermore, the descriptions of both Urban Living Labs and Urban Transition Labs as "arenas" suggest that labs are to be created, designed and constructed as spaces from the "outside". This can be seen in the example of Concept Village House, positioned as an exemplar site in the city of Rotterdam (Burbridge et al., 2017). Similar views are echoed by Evans and Karvonen (2014) who argue that urban laboratories necessitate the creation of spaces in order to function as a mode of governance.

3.3.2. Process

Sustainability-oriented labs include a range of processes, methods and tools deployed at a local level for achieving particular ends. It therefore relates to the "how" of labs practices. Labs show diversity in their processes of deliberation and moving from e.g. identifying and structuring problems and challenges, to developing and experimenting with solutions, evaluation as well as scaling and transfer. The Berlin Tegel Airport case (Bahu et al., 2015) begins at the level of needs, assuming that they can be incorporated through the co-creation of a particular technology. In contrast, T-Lab Xochimilco begins at the level of a complex and contested problem (Charli-Joseph et al., 2018). The starting point then accommodates additional perspectives in problem framing in a particular context. These two cases illustrate a spectrum that exists regarding the nature and intent of labs, as well as reasoning for the methods and tools incorporated into their processes to stimulate learning, analysis and action. UTL Ghent, for instance, works through a sequence of steps and activities of (i) analysing the system, (ii) envisioning, (iii) exploring pathways, (iv) experimenting, (v) assessing and (vi) translating (Nevens and Roorda, 2014).

3.3.3. Organisation

The organisational dimension of sustainability-oriented labs relates to how actors and resources are mobilised in certain directions and for certain purposes. This dimension therefore encompasses the "who" of lab practices. Labs are often owned and funded through a plethora of multi-stakeholder arrangements. For

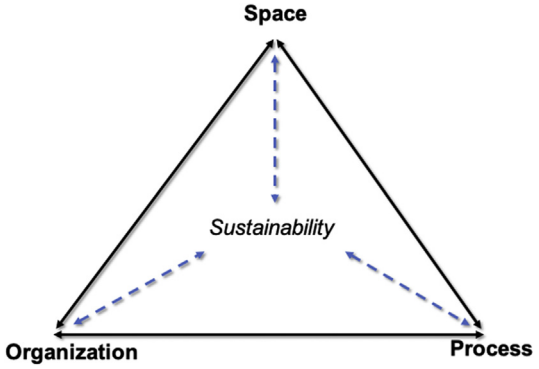

Fig. 5. Key lab dimensions of space, process and organisation. Solid lines in the visual triad denote practical relations between spatial, procedural and organisational dimensions. Dashed lines indicate interrelatedness with sustainability as a dynamic normative property.

[6] Change Laboratory here should not be confused with Stanford Change Labs, an innovation approach rooted in systems thinking and introduced into SES research by Westley et al. (2011) and Olsson et al. (2014). Change Laboratory in this paper refers to a well-established intervention method developed by Yrjö Engeström et al. This approach is elaborated upon and traced by Engeström (2001) and builds upon CHAT from the 1970s.

example, Livewell Yarra (Sharp and Salter, 2017) and Cahors Living Lab (Claude et al., 2017) are initiated by hybrid partnerships that involved university partners, municipal stakeholders, technical partners and cultural services stakeholders. Home Energy Management systems (Schwartz et al., 2015), on the other hand, includes a management team of researchers that are accompanied by a "user testing panel". More broadly, there are discussions within the sustainability transitions community on labs as a *particular mode of governance*. This reference suggests sustainability-oriented labs reflexively interact with existing knowledge, technology and policy relations through the involvement of a variety of different actors in society. For instance, Urban Living Labs are often highlighted as a new form of climate governance; Evolutionary Learning Labs actively engage multiple stakeholders in grasping complex challenges; Urban Transition Labs are framed as forms of reflexive governance.

3.3.4. Interrelations amongst characteristics

While each key dimension enables a characterisation of distinctive lab practices, they can also be seen as interrelated. In other words, labs are simultaneously spatial, procedural and organisational in their practice. For example, Trial and Error exists primarily as a material space for making and repairing. This space can change in location and format – as has been the case during the lifetime of this lab – however the requirement of a bound location is key for stakeholders to meet and organise, as well as for processes to unfold (Hector, 2018). Equally, there are examples of a variety of labs that develop generic methodological processes in different spatial contexts (Nevens et al., 2014; Banson et al., 2016) and with different organisational set-ups. Other labs were born out of the need to organise around specific local issues (*see* Mooi Mooier Middeland in Puerari et al., 2018). In addition, we found labs that engage in processes relevant for sustainability transitions research through an explicit focus on (Loorbach et al., 2017): 1) how sustainability is negotiated in particular contexts, 2) how multiple perspectives are incorporated in approaching, understanding and addressing sustainability challenges, 3) whether and how systems-approaches are used, and 4) how futures are approached in sustainability-contexts through e.g. visions and processes of envisioning.

3.3.5. Sustainability

Labs are not only diverse in – and can thus be characterised according to – their practices regarding space, process and organisation. Given the ways in which an understanding of sustainability shapes and is shaped by the spaces, processes and ways of organising in labs, we consider sustainability to be a dynamic normative property.[7] There are a multitude of ways that these initiatives describe, interpret and negotiate what sustainability is. We surface two distinctions that may be particularly useful for thinking about the sustainability-orientations of labs: the distinctions between sustainability as 1) narrow or broad in interpretation and 2) closed or open in definition.

Firstly, lab foci on consumption of energy are examples of a narrow interpretation of sustainability (Lancaster University Campus Lab *in* Bates and Friday, 2017). A broader interpretation of sustainability is illustrated by both a broader focus within a particular topic, as well as by considering several sustainability issues simultaneously. The University of Wisconsin case (Lindstrom et al., 2015) is an example of the former in that it broadens energy to include education about consumption. As examples of the latter: Livewell Yarra referred to sustainability as individual GHG emissions and low-carbon living (Sharp and Salter, 2017); RWL Mirke framed sustainability as a central matter of well-being (Rose et al., 2017); and in 'Together Peltosaari' sustainability is understood as social cohesion (Buhr et al., 2016). Secondly, there is evidence that various labs treat sustainability as a closed issue, such as in the University of Cape Town Lab (McGibbon et al., 2014). Here, sustainability is reduced to energy consumption at the building level. In contrast, sustainability can also be viewed as an open concern that requires additional meaning in context. In Evolutionary Learning Lab Haiphong (Nguyen et al., 2014), the particularities of sustainability are jointly defined by stakeholders during stage 1 of an Evolutionary Learning Lab methodology.

4. Discussion

Here, we engage in a broad discussion by building upon results from our main research question: How can sustainability-oriented labs in real-world contexts be understood? This is structured according to results introduced in section 3: descriptive overview at a sample level, different lab research communities, and key dimensions to characterize lab practices.

4.1. Overview: labs as research-change intervention hybrids

Descriptive results from 3.1 highlight that sustainability-oriented labs are geographically, thematically and institutionally diverse. Here, we introduce and discuss two additional observations regarding their distribution and overall form.

Firstly, despite the international spread of sustainability-oriented labs reported on in case studies, their empirical distribution is concentrated to the Global North and, in particular, to Northern-European contexts.[8] Similar phenomena have been reported earlier for scholarly publications in the field of sustainability transitions at a discourse level (Chappin and Ligtvoet, 2014). This leaves room for at least two interpretations. First, that lab-like initiatives have until this point developed in the Global North, particularly Europe. Potential factors for this could include the focus of available funding sources, established research communities and infrastructure for the local implementation of labs, and broader cultural or political developments easing such governance efforts (geographical bias). Second, labs developed in globally Southern or Northern American contexts might have been less researched via case research or reported outside the lab discourses (representational bias).[9] In either case the appropriateness of lab-like initiatives for other geographical contexts remains underexplored in practical and research terms. For instance, does the over-reliance on Dutch, Swedish and German initiatives produce an academic preference that limits the possible generalisation of insights to other contexts? Both observations invite for future research into lab-related approaches from other geographical contexts, as well as of the applicability of existing lab approaches in other contexts.

Secondly, labs are frequently subject to framing as either research objects or change-oriented interventions. This may reflect the twin ambition of generating both complementary knowledge

[7] With interrelations between sustainability and spatial, organisational and procedural dimensions being many-sided, for reasons of space we only briefly sketch them here.

[8] Note that some very recent exceptions with a global south focus (e.g. Pereira et al., 2020) were not part of this review as they fell outside the time-scope set (published until 2018).

[9] Please for instance note a recent special issue on transformative spaces in Ecology and Society, which, due to the different framing was not included in this review focusing on "labs" (Pereira et al., 2018).

to foster (transitional) processes of change and, at the same time, enrich our understanding of them. While this dual aim is more central to the definition of particular lab approaches, for instance Real-World Laboratories (Schäpke et al., 2018), it can be observed as a general pattern shared by a variety of approaches. Despite some separations that are presumed to exist here (societal vs scientific knowledge, understanding vs changing, knowing vs doing), there is also room for interpretation. Stances taken in some labs are suggestive of a view where understanding is not only foundational in pursuing transitional change, but it constitutes a central mechanism in changing. This view carries implications for the performative nature of labs; their spaces, process, ways of organising, as well as our attempts to comprehend their impacts, are underpinned by dissolving or re-ordering certain distinctions between knowledge and action - from "understanding then changing" to "understanding by changing" and "changing by understanding" (Stirling, 2016; Van Kerkhoff and Lebel, 2006).

Researcher engagement and roles operate are both diverse and adaptive in sustainability-oriented labs. They range from more distanced observation of activities (in the case of 'Temporary', *in* Hector, 2018) to more engaged facilitation of processes and knowledge exchange ('ELL Haiphong', *in* Nguyen et al., 2014). It should also be recognised that there are labs in this study that operate without the support of or co-ordination from research (for instance, Manor House PACT *in* Astbury and Bulkeley, 2018). They are in this sense primarily rooted in respective, societal contexts oriented towards an acute demand (i.e. societally driven, as opposed to research-driven). We see additional instances of role dexterity, where researchers assume multiple roles not only across process stages, but also simultaneously (see 'Challenge Lab', *in* Larsson and Holmberg, 2018). Moreover, these roles are context-related, as well as guided by particular views on what science is or should be (Fazey et al., 2018). As these findings fall outside of the scope of the review, future research could entail more focused investigation of such dynamics and relations in sustainability-oriented labs, building upon existing studies of researcher roles in transitions (Wittmayer and Schäpke, 2014; Rose et al., 2017).

4.2. Lab discourses: pluralising theory and practice

As highlighted in 3.2, there are at least 7 discrete research communities where sustainability-oriented labs are developing. Here, we firstly discuss a range of theoretical and applied approaches before exploring their relations and analytical movements. Certain approaches are partly distinguishable due to their reliance upon specific, non-overlapping constructs in their conceptualisation. Such constructs range from the role of the user in design processes in Living Labs to fragmented mental models in Evolutionary Learning Labs. Other concepts can be linked to several different lab approaches, with divergence as to how they are understood and practiced. As an illustration, Urban Living Labs is the most frequent conceptualisation and draws heavily from user-innovation research (co-creations, usability, innovation ecosystem). In more recent years, they have begun to evolve conceptually and practically by attending to framing, learning and power, all three of which are advocated in recent papers on sustainability transitions (Loorbach et al., 2017; van Mierlo and Beers, 2018). In addition, pluralising theory and practice can allow for exchanges between so far largely unrelated discourses on labs. For example, Cultural-Historical Activity Theory (CHAT) presents a systemic theory of change that explicitly aims to understand and transform undesirable systems. It also holds a combined focus on overcoming contradiction as a condition for transgressive learning processes. These elements form the basis for the Change Laboratory as a real-world approach, advocated as a robust methodology that can support in exploring transformative change (Macintyre et al., 2018). By considering CHAT in relation to current theories in sustainability transitions (Sovacool and Hess, 2017), it may be possible to begin jointly developing insights and complementary lenses with an interest in integration.

This review highlights how different sustainability-oriented lab conceptualizations develop through theory-concept elaboration and practical experience. Many conceptualizations iterate between theoretical and empirical work but make these movements in different ways. Opening the perspective beyond individual lab approaches and discourses shows that there are both: labs that follow a more grounded-theory oriented epistemology in their development (as called for by Jaeger-Erben et al., 2018); as well as others that build on strong theoretical foundations (as called for by Jahn and Keil, 2016). Some originate from extensive conceptual reasoning (e.g. on reflexive governance of complex system transitions as in Transition Management or mentioned in CHAT theory underlying Change Laboratory) before being "empiricised" through empirical cases; others draw upon 'actually existing' initiatives to generate novel conceptualisations (such as Urban Living Labs). Real-World Laboratories appear as a middle ground, starting from a series of funding calls and leading to empirical experiences which are used to further conceptualisations. Identifying the above movements is necessary but not sufficient in grasping the evolution of lab discourses. It encompasses not only how theory-practice approaches are developed in relation to each other, but also how their trajectories are shaped by a range of political, cultural and institutional forces inside and outside of academia. Exploring different starting points of the learning cycle may, if based on complementary epistemologies, serve a number of useful purposes. In the case of theory, it allows for more flexibility in both comprehending and informing lab practices, guided by the notion that "there is nothing as practical as a good theory" (Lewin, 1943). Practice, in turn, can specify empirical conditions and contexts for the exploration of particular phenomena of interest, resulting in favourable theory outcomes.

4.3. Linking lab dimensions to transitions: geography, innovation, governance, and sustainability

Here we relate findings on lab dimensions (elaborated in 3.3) to current research strands in the field of sustainability transitions. In particular, we focus on four relevant strands: 1) geographies of transitions, 2) politics and power in transition governance, 3) innovation and actor and perspective integration, and 4) sustainability as a normative aspect of transitions.

4.3.1. Linking to geography in sustainability transitions

Firstly, we presented sustainability-oriented labs as spatially discrete, bounded settings within which experimentation is presumed to occur. Here, it is possible to link these labs to *transition geographies* through an expanded consideration of space, place and scale in transition studies (e.g. Truffer et al., 2015; Coenen and Truffer, 2012; Raven et al., 2012). It is beneficial to view labs not as spatially bounded or static in their form, but rather as fluid, dynamic and emergent (Leander et al., 2010; Thomas, 2010). Such a stance disrupts the view of labs as separate analytical entities to be implanted, injected or designed. It also counters simplified notions of labs as a natural "starting point" of a change process. Rather, they exist within a vibrant network of relations and interactions that extend outside analytical boundaries that researchers construct. In some senses, the lab represents an internal contradiction – a setting claimed to be bound in time and space, but inevitably interacting with the fluidity of its socio-spatial context (Evans and Karvonen, 2011). The above reflections therefore invite analytical

moves to spatialise labs in new ways. This could function as part of a broader discussion regarding how explicitly spatial theory can be represented in sustainability transitions research in line with relational, multi-scalar and mobilities-based methodological approaches (Levin-Keitel et al., 2018; Hansen and Coenen, 2015).

4.3.2. Linking to innovation in sustainability transitions

Secondly, labs host and/or design a variety of different processes. Here, we frame labs within broader conversations around innovation and participation in process development. There is a growing curiosity concerning whether conventional attitudes to innovation are intrinsically at odds with the ethical or systemic dilemmas present in sustainability transitions (Blok and Lemmens, 2015; Seyfang and Smith, 2007). Stark differences may exist in innovation processes that occur in the development of single technologies, services and products, as opposed to those that encompass the multi-actor, multi-factor and multi-level nature of systems within which they are embedded (Elzen and Wieczorek, 2005). This tension is aptly voiced by Blok and Lemmens (2015):*"If we conceive a grand challenge like sustainable development for instance in such a way that it affords a systems change, a wholly different set of innovations is at stake than if it is defined at a product level and only involves innovations in order to substitute depletable resources"* (pg. 22). Additionally, innovation may need to be reconceived in order to move beyond the co-creation of products, towards the co-creation of new worlds and desirable futures (Gergen et al., 2004) by change of overall societal systems. Of relevance for labs and transitions are therefore the efforts to question what innovation is, could be or should be. These include those that situate the product and service innovation within a systems perspective (Levin-Keitel et al., 2018; Raven et al., 2012), as well as those that broaden the scope on the objects of innovation, including social innovation (Avelino et al., 2017; Wittmayer et al., 2019), governance innovation (Griffin, 2010) and responsible innovation (Stilgoe et al., 2013).

Research in sustainability transitions encourages an integrative approach to different actors and perspectives. This is usually claimed to be achieved by co-creation, participation or extensive forms of multi-actor engagement in labs. However, these ideals can be perceived and practiced across contexts, with their implications further connected to broader socio-technical configurations. Additionally, they are not neutral, but outcomes of a decision-making process that occurs in advance (Stirling, 2006). For example, various forms of participatory innovation processes can either reinforce or challenge existing "rules of the game" in transitions and transformations (Smith and Raven, 2012), to suppress dissent or to favour dominant socio-technical configurations (Shove and Walker, 2007). Feola (2015) highlights the tensions of relying on participation for transformation by highlighting that the outcome of deliberative scenarios might lean more towards incrementalism. Moreover, participation can be linked to political landscapes that favour short-term gains over longer-term systemic effects. Such tensions therefore suggest the need to critically assess the contextual conditions of participatory processes in labs as they establish the frames for how transformative innovations are developed and carried out.

4.3.3. Linking to governance in sustainability transitions

Thirdly, labs are often viewed as innovative forms of governance. Consistent with discussions in sustainability transitions (Meadowcroft, 2009; Raven et al., 2016; Shove and Walker, 2007), such a view also acknowledges that there is a *politics to labs*. Labs themselves are subject to micro-politics in their ambitions, design, practice and evaluation. For example, any attempt to generate evaluative conclusions is shaped by the methodological choices that are adopted, as well as the values implicit in evaluation. With this in mind, there is a need to unpack the collaborative arrangements that exist in labs, as well as the dynamics that shape and structure these arrangements. Investigating micro-politics in lab practice and enquiry accommodates the view that they are contested and pluralistic settings to engage with change processes characterised by uncertain outcomes. It also builds upon a critical recognition within transitions that bringing stakeholders together should not be equated automatically with transformation (Budwig, 2015; Van Kerkhoff and Lebel, 2006), and that *"not all experiments are aimed at socio-environmental progress, nor are they all progressive"* (Caprotti and Cowley, 2017, pg. 1447). Overcoming such concerns therefore implies a shifting of micro-politics from its tangential role in of "context" to a more dedicated position, guided by questions such as: Under which conditions do labs emerge? How is participation valued and actually practiced in lab activities? How is ownership of labs negotiated?

4.3.4. Taking sustainability seriously in sustainability transitions

Fourthly, this study highlighted a variety of considerations for "*sustainability*" that are present in this sample of labs. For some, sustainability was treated as an exogenous environmental challenge to be solved through particular technological systems. For others, it was treated as a contingent manifestation of a complex, multi-dimensional phenomenon. As sustainability was incorporated into a review, one could argue that these findings occur at a level of aggregation that conceals the qualitative nuances of interpreting sustainability in local contexts. This limitation is even more important when considering that sustainability is viewed as a contested concept (Jacobs, 1999; Robinson, 2004). Within sustainability transitions, research is now attempting to account for normative objectives – such as sustainability – as worthy of analytical attention in its own right (e.g. Rauschmayer et al., 2015; Köhler et al., 2019). Such efforts include the work of Raven et al. (2017) who, when commenting on the importance of unpacking divergent and pluralistic perspectives on sustainability, advocate "*this holds important implications for notions of transitions and experimentation in which sustainability or its technological implications are held to be self-evident*" (pg. 587). Not only is sustainability engaged with by the "where, how and who" of lab practice; it is also produced and defined by these very choices. Sustainability in this sense is claimed here to be a dynamic normative property, changing through the course of different labs and encompassing "emergent ambivalences and qualities" (Walker and Shove, 2007; pg. 220). Relatedly, in this review we provide a relevant collection of sustainability-oriented labs that comprise unique spaces, processes and ways of organising around sustainability. In suggesting avenues for future research, this review therefore provides conditions to zoom in on and unpack the particularities of sustainability in sustainability-oriented labs.

5. Conclusion and future research

This paper sought to explore labs, as a particular form of change-oriented initiative, that have an explicit orientation towards sustainability. This was facilitated by the use of a systematic review process and exploratory mixed-methods analysis. We believe that the findings in this study advance knowledge on the phenomenon of labs in at least two different ways. Firstly, the results from this review represent an empirically novel contribution to the field of sustainability transitions and transformations. It has done this by weaving together this collection of labs from across seemingly disparate fields of research and practice. Secondly, we present a heuristic on three interrelated practical dimensions that may offer promise in comparing various lab designs, and in linking to

transition geographies, processes and governance that are of salience in the field of sustainability transitions. This triadic understanding of labs – as spaces, processes and ways of organising, as well as the positioning of sustainability as a dynamic normative property – therefore offers promise in opening up and reflecting over the design of labs, as well as linking favourable and unfavourable elements to particular outcomes.

In conclusion, we broadly map out research perspectives that may complement this review. Firstly, we suggest that findings here can benefit from studies that zoom in and unpack sustainability as not only normative, but also dynamic in definition and interpretation. Complementary perspectives can thereby pay attention to how sustainability is framed, negotiated and decided upon in sustainability-oriented labs. By doing so, it may be possible to uncover the nature of establishing "what sustainability is" in a particular context, thus illuminating the winners and losers, compromises and sacrifices and what "is not". In linking to transitional perspectives, there are opportunities to explore how labs interact with system dynamics across scales, in particular those at the interface between global challenge and local context. Finally, the collection of empirical cases presented in this review can facilitate in-depth case-based research and cross-case comparison for greater contextual coverage, providing fertile ground for theory-practice development.

Authors contributions

All authors contributed equally to the overall conceptualisation (RQs, aims, problem statement) and methodological setup of the study. Author 1 was primarily responsible for the curation of data, manuscript writing and coordinating contributions across all co-authors. Authors 1, 2 and 3 jointly contributed to formal analysis of the data. Authors 2 and 3 drafted particular sections of the paper. Authors 2, 3 and 4 provided comments and feedback in the drafting and finalization of the manuscript.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123202.

Appendix A. List of cases with paper sources

Case names	Description of specific lab (*From source*)	Source text
Concept House Village Lab	"Concept House Village Lab operates as a test-bed for sustainable building technologies and innovative approaches to building retrofitting in the area of Heijplaat in Rotterdam. This Lab is a place where innovative houses, products, and systems are tested together with and by the (temporary) occupants, while experimenting with new approaches of urban development."	Burbridge et al. (2017)
Kenniswerkplaats LeefbareWijken	"The lab acts as a knowledge broker between municipality and university and works through the co-creation of knowledge with real-life problems as a starting point."	Puerari et al. (2018)
Marconia	"Marconia is a cooperative that is located on a 30,000 m^2 old marshalling yard close to a harbour area of Rotterdam."	Puerari et al. (2018)
Mooi Mooier Middelland	"An experiment with co-creation between citizens and the municipality, financed with seven million euros for a period of three years."	Puerari et al. (2018)
Zorgvrijstaat	Zorgvrijstaat is an association that aims to give health assistance, mainly psychological and psychiatric, based on neighbourhood structures.	Puerari et al. (2018)
Berlin Tegel Airport - UTR	"The TU Urban Lab served as a platform for incorporating the user perspective as well as furthering the development of specifications for the spatial energy model through dialogue between all involved stakeholders."	Bahu et al. (2015)
Blue City Lab	"Blue City Lab is a Lab located at an iconic site, an abandoned swimming pool in the city of Rotterdam, since 2015. The building now functions as a platform for co-creation, events, and experiments with blue and circular economy initiatives."	Puerari et al. (2018)
Cahors Living Lab	In the framework of the ENERPAT Project, an EU Interreg SUDOE has now been funded. Three European cities (Cahors, France; Vittoria, Spain and Porto, Portugal) are working on three different demonstrator buildings in typical ancient centers and will include several Living Labs at the different stages of the project (before, during and after refurbishment) and when the buildings are occupied.	Claude et al. (2017)
Canton Basel-Stadt ULL	"Since 2001, this lab has united scientists with government and industry practitioners to exploit the Canton Basel-Stadt as a testing arena for emerging built environment, mobility and energy technologies to advance progress towards a "2000-Watt Society"	Marvin et al. (2018)
Carbon Generalized System of Preferences scheme (GSP)	By policy design, registered citizens in the scheme can trade personalized Carbon Coins on social media platforms, official website or an App. Carbon coins are earned by performing carbon saving behaviour and used as vouchers to redeem commercial services and products.	Marvin et al. (2018)
Cat Ba Biosphere Reserve Learning Lab	"Learning laboratory for sustainable development: the learning laboratory is a process as well as a setting and place in which a group of stakeholders can think and learn together. It is an environment where policymakers, managers, local people, and researchers collaborate and learn	Nguyen et al. (2011)

(*continued on next page*)

(*continued*)

Case names	Description of specific lab (*From source*)	Source text
	together to understand and address complex problems of common interests in a systemic way. The ultimate goal is to achieve coherent actions towards sustainable outcomes."	
Centre for Interactive research on Sustainability, Vancouver	"CIRS is a Living Lab on the University of British Columbia (UBC) campus (the term 'regenerative' here is used interchangeably with 'net positive')"	Coleman and Robinson (2018)
Challenge Lab	"In the Challenge Lab, students take on complex societal sustainability challenges in collaboration with others associated with the five regional knowledge clusters in West Sweden"	Larsson and Holmberg (2018)
Change Laboratory Zimbabwe	"Livelihood Security in a Changing Environment: Organic Conservation Agriculture"	Mukute et al. (2018)
Evolutionary Learning Lab, Haiphong, Vietnam	"The ultimate goal is to achieve coherent actions directed towards sustainable outcomes."	Nguyen et al. (2014)
Ghana Evolutionary Learning Lab	"The Evolutionary Learning Lab a methodology for creating informal learning spaces or platforms for managing complex issues"	Banson et al. (2016)
Ghent Urban Transition Lab	No definition	Nevens and Roorda (2014)
Greater Accra Region of Ghana	"Uses systems thinking tools, including causal loop diagrams and Bayesian belief network modelling, to develop new structural systems models whereby stakeholders can determine the components and interactions between the structure, conduct and performance (SCP) of the agricultural sector in Ghana"	Banson et al. (2018)
Green Office UTM Campus Sustainability	"Living lab framework applied in UTM CS (Universiti Teknologi Malaysia Campus Sustainability). Running a green office with student involvement. Hence, campus as: "responsible and optimized resource management, innovative environmental and ecosystem management, efficient energy management and leadership commitment and campus-wide participation"	Zen et al. (2016)
Green Source Environmental Volunteer Association	"The green source houses urban environmental protection activities based on grassroots activism. It operates on new ways of citizen engagement and other grassroots organisations, innovative lobbying techniques and local agenda setting and self-sustained financing."	Marvin et al. (2018)
Home Energy Management System (HEMS), North-Rhine Westfalia	No definition	Schwartz et al. (2015)
HSB Living Lab	"A unique international facility on the Chalmers University of Technology campus in Gothenburg, where researchers and societal actors can co-create ideas and initiatives for products and services which will enable sustainable living. " ""The building is home to 33 residents, as a research and demonstration area. It is equipped with 2000 sensors measuring, for example, electricity, heating and water flows as well as the indoor climate, the location of residents inside the building and the weather conditions outside the building.""	Andersson and Rahe (2017); Burbridge et al. (2017)
Knowledge Dialogue Northern Black Forest (WiNo)	No definition	Parodi et al. (2018); Pregernig et al. (2018)
Lab course, British University of Egypt	"The methodology applied in this pilot course is learning by experimentation in an urban living lab environment"	Dabaieh et al. (2018)
Lancaster University	"Using existing IoT infrastructure to create a campus scale "living laboratory" for promoting energy savings and environmental sustainability."	Bates and Friday (2017)
Livewell Yarra	Livewell Yarra was an urban living lab that enabled community participation to trial experiments in low carbon living with an emphasis on carbon reduction and wellbeing.	Sharp and Salter (2017)
Manor House PACT (Prepare, Adapt, Connect, Thrive)	"Manor House PACT has functioned explicitly as a laboratory for learning, a space within which "trial and error" approaches have been welcomes, with processes of translation, learning, scaling and empowering given space to flourish from the grassroots. At the same time, it has relied on the strategic intervention of national funding, as well as the involvement of municipal actors."	Astbury and Bulkeley (2018)
New light on Alby Hill	"Testing of new LED lighting technologies and co-design of light installations."	Buhr et al. (2016); Menny et al. (2018)
Nexthamburg	"Creating a virtual and physical space to discuss ideas." Crowdsourcing platform	Menny et al. (2018)
Oxford corridor, Manchester	"The corridor is a bounded space where a public-private partnership comprised of the City Council, two universities and other large property owners is redeveloping the physical infrastructure and installing monitoring equipment to create a recursive feedback loop intended to facilitate adaptive learning"	Evans and Karvonen (2014)
Pecan Street Project PSP	Pecan street in Mueller area was selected because of the uniformity of the houses and the standards requiring energy-efficient buildings. Here, various smart grid and smart home technologies were implemented in an urban neighbourhood as a testbed, monitoring and analysing energy consumption data.	Levenda (2018)
Peltosaari - "Together more"	"Together More" launched processes for co-creating a more attractive neighbourhood that would appeal to residents, visitors, and other stakeholders.	Buhr et al. (2016)
Resilience Lab Carnisse	Veerkracht Carnisse (an urban living lab) is an urban regeneration experiment that focused on empowering local communities and fostering urban sustainability and resilience with a place-making orientation in mind.	Frantzeskaki et al. (2018)
RLL Karditsa	"...Is a "local partnership" that focuses on projects of social interest and environmental protection."	Giannouli et al. (2018)
RWL Arrenberg	"Essbarer Arrenberg promotes sustainable, local nutrition for the Arrenberg district through urban farming, food-sharing and restaurant days."	Rose et al. (2017)
RWL Mirke	"In the Mirke RWL, a forum that aims to integrate all relevant civil and municipal stakeholders of district development for the purpose of local well-being transformation is supported"	Rose et al. (2017); Wanner et al. (2018)
RWL Oberharmen & Wichlinghausen	"The Oberharmen & Wichlinghausen RWL focuses on vacant apartments in this area and aims to create solutions to care for them with the help of tenants who pay below standard but maintain the facility"	Rose et al. (2017)
SABER	In the SABER project, a Living Lab approach was applied and used to support the innovation and development process of the SABER concept as a whole. Saber is a product and a service concept aiming to support energy saving in buildings. In this project, the focus was on development of a high-fidelity prototype and of the final system.	Ståhlbröst (2012)
Sewing Cafe Dietenheim	"A living lab research project by the University of Ulm and the University of Applied Arts Reutlingen, initiated for research on textile industries".	Hector (2018)
Seychelles Sustainability learning Lab	"A prototype of a sustainability learning lab (SLL) that we offer in the global South. We use the term "lab" metaphorically in the broad sense of an inspiring and creative learning space where people	Krütli et al. (2018)

(*continued*)

Case names	Description of specific lab (*From source*)	Source text
	(e.g., from university, civil society, government) meet, share ideas, and create new knowledge in the context of sustainability."	
Smart Nasha	"An Industrial-Academic-Research alliance based on tight policy statutory basis led by a governance organized NGO to perform smart city experiments in special economy district"	Marvin et al. (2018)
SustLabRWE Bottrop	"SustLabNRW: a real-life experiment on user-centred development of sustainability innovations around the home, located in the Ruhr area in North Rhine Westphalia (NRW). Part of larger SustLabNWE project."	Burbridge et al. (2017)
T-City Friedrichshafen	"Building a test bed for smart city technologies and projects"	Lee et al. (2011); Menny et al. (2018)
Temporary	"Temporary (https://temporary.fi/) was a one-year hybrid project between a culture lab and co-working space in Helsinki, funded through cultural grants given to the two organizers and free for anyone to attend"	Hector (2018)
The Future City Lab	"To achieve such change, the University of Stuttgart established an interdisciplinary team working closely together with institutional practice partners, such as the Municipality of Stuttgart"	Parodi et al. (2018); Pregernig et al. (2018)
The SubLab North-Rhine Westfalia	"Consists of a Smart Home Lab, real home environments and showcase apartments in the city of Bottrop"	Burbridge et al. (2017)
Trial and Error	"Trial & Error (https://www.trial error.org/) is a Berlin- based culture lab that wants to enable various DIY initiatives by providing a space for them."	Hector (2018)
Ubigo	"Piloting of a travel broker service."	Menny et al. (2018)
University of Cape Town Lab	"A living laboratory to iteratively test database models, with all the challenges of managing people as well as technology."	McGibbon et al. (2014)
University of Wisconsin	"Lighting upgrades to concepts of sustainability. "UW-Madison campus as a living-learning laboratory where these concepts were brought to life for students"	Lindstrom et al. (2015)
Urban Transition Lab 131 (R131)	"The lab, and in particular the R131 location Zukunftsraum (Future Space for Sustainability and Science), serves as a networking platform and infrastructure, enabling sustainability experiments arising from the district's needs and interests."	Parodi et al. (2018); Singer-Brodowski et al. (2018)
Washing home labs	"Home Labs are collaborative, transdisciplinary experiments focusing on disrupting domestic water consumption based on a research led-exploratory living lab approach"	Davies (2018)
Xochimilco T-Lab	"The T-lab aims to be an emergent space for reflection, reframing, and the formation of new pathways for change."	Charli-Joseph et al. (2018)

Appendix B. Search strings for review

Web of science

((TS=((Sustainab*) AND ("living lab*" OR "social lab*" OR "urban living lab*" OR "urban transition lab*" OR "transition arena*" OR "campus lab*" OR "urban sustainability transition lab*" OR "policy lab*" OR "innovation lab*" OR " learning lab*" OR "city lab*" OR "urban lab*" OR " future lab*" OR "transition lab*" OR "challenge lab*" OR "sustainability lab*" OR "transdiscipli* lab*" OR "design lab*" OR "home lab*" OR "transformation lab*" OR " real-labor*" OR "real-world lab*" OR " change lab*" OR "T-lab*") NOT "labor" NOT "social labor" NOT "collaborate" NOT "available" NOT "living labour" NOT "living labor" NOT "living label" NOT "labral" NOT "clinic*" NOT "animal* experiment*" NOT "label*"))) *AND* **LANGUAGE:**(English) *AND* **DOCUMENT TYPES:**(Article) - **147 results**.

Scopus

(TITLE-ABS-KEY (("Sustainab*") AND ("living lab*" OR "social lab*" OR "urban living lab*" OR "urban transition lab*" OR "transition arena*" OR "campus lab*" OR "urban sustainability transition lab*" OR "policy lab*" OR "innovation lab*" OR "learning lab*" OR "city lab*" OR "urban lab*" OR "future lab*" OR "transition lab*" OR "challenge lab*" OR "sustainability lab*" OR "transdiscipli* lab*" OR "design lab*" OR "home lab*" OR "transformation lab*" OR "real-labor*" OR "real-world lab*" OR "change lab*" OR "T-lab*") AND NOT "labor" AND NOT "social labor" AND NOT "collaborate" AND NOT "available" AND NOT "living labour" AND NOT "living labor" AND NOT "living label" AND NOT "labral" AND NOT "clinic*" AND NOT "animal* experiment*" AND NOT "label*")) AND (LIMIT-TO (LANGUAGE, "English")).

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