Building as a Living Lab:

Context and Practices for Research on Environmental Sustainability in Living Laboratories

AAR4993- Master's Thesis

Trondheim, June 2022, Maryam Rezaee
Supervisor: Prof. Francesco Goia

Norwegian University of Science and Technology
Department of Sustainable Architecture

NTNU-Trondheim
Norwegian University of
Science and Technology

Abstrakt

«Living lab» er en nyere arena som har som mål å legge til rette for innovasjon ved å involvere brukere i utviklingen av produkter og tjenester. Bygninger skaper en virkelig kontekst for å studere interaksjoner mellom menneske og teknologi og gir en kontrollerbar plattform for å teste teknologier under et ly. I løpet av de tre tiårene det har utviklet seg, har forskere gjort store anstrengelser for å dekke mange aspekter av dette fenomenet. Imidlertid er litteratur om bygging av levende laboratorieaktiviteter og hvordan de kan støtte denne brukersentriske tilnærmingen for å forbedre miljømessig bærekraftspraksis sjelden. Derfor er det behov for å utforske innflytelsesrike faktorer, metoder og potensielle utfordringer i bærekraftig bygging av levende laboratorier for å gi et rammeverk for deres praksisbaserte aktiviteter.

Denne forskningen er utført ved en systematisk litteraturgjennomgang og kvalitativ og kvantitativ analyse samt spørreskjema; og den gjennomføres på tre nivåer; Først definerer den tre hovedkonsepter basert på BLL-aktiviteter. Deretter, med et spesielt fokus på miljømessig bærekraftig bygning av levende laboratorier, identifiserer den ulike tilnærminger og metoder som brukes for å oppnå miljømessige bærekraftsmål. Til slutt, ved hjelp av dyptgående komparative casestudier, identifiserer den ulike faktorer som påvirker nivået av brukerinvolvering under SBLL-eksperimentene, for eksempel metodene for å introdusere konseptet til brukerne, metodikk for brukerrekruttering, beleggstid for eksperimentet, og nivået på brukernes aksept og tilfredshet. Til slutt, basert på funnene, gir den noen praktiske retningslinjer for å øke kvaliteten på brukerinvolvering i SBLL-praksis.

Nøkkelord: Building living lab, sustainable living lab, brukerinvolvering, menneske-teknologi interaksjon

Abstract

“Living lab” is a recent arena that aims to facilitate innovation by involving users in the development of products and services. Buildings create a real-world context to study human-technology interactions and provide a controllable platform for testing technologies under a shelter. During the three decades of its development, researchers have made great efforts to cover many aspects of this phenomenon. However, literature on building living lab activities and how they can support this user-centric approach to enhance environmental sustainability practices are rare. Hence, there is a need to explore influential factors, methodologies, and potential challenges in sustainable building living labs to provide a framework for their practice-based activities.

This research is conducted by a systematic literature review and qualitative and quantitative analysis as well as questionnaire; and it is conducted on three levels; First, it defines three main concepts based on BLL activities. Then, with a particular focus on environmentally sustainable building living labs, it identifies various approaches and methods employed to achieve environmental sustainability goals. Finally, by in-depth comparative case studies, it identifies various factors which affect the level of user involvement during the SBLL experiments, such as the methods of introducing the concept to the users, methodologies for users recruitment, occupancy time for the experiment, and the level of users’ acceptance and satisfaction. In the end, based on the findings, it provides some practical guidelines to increase the quality of user involvement in SBLL practices.

Keywords: Building living lab, sustainable living lab, user-involvement, human-technology interaction

Acknowledgments

This master thesis is based on the research conducted on the living lab topic between December 2021 and June 2022, and it is the last piece of work after two years of studying Sustainable Architecture at NTNU. I have learned so many lessons from this research work, which would greatly support my future academic journey.

I wish to give a very warm thank you to Prof. Francesco Goia, who supervised my thesis work. Thanks for the perfect supervision and many thanks for your patients and support during this time. I enjoyed every moment of the research work which was accompanied by your positive motivation, valuable guidance, and academic experience.

To all my colleagues and group mates during the study in this field, thanks for all your collaboration in the team works, I learned a lot from you.

To all my teachers, advisors, and professors both from NTNU and my home country –Iran- who were the most influential parts of this journey. If it were not for your support, I wouldn't be in this position.

And finally, and most importantly to my family especially my mother and father who are the most precious properties of my life… My heart beats just for you in every moment of life in exile.

Table of Contents

List of figures

List of tables

Abbreviation

ENoLL	European Network of Living Labs
BLL	Building Living Lab
SBLL	Sustainable Building Living Lab
SLL	Sustainable Living Lab
LL	Living Lab
ICT	Information & Communication Technology
AAL	Ambient Assisted Living
ZEB	Zero Emission Building
BEMS	Building Energy Management System

Introduction

The term “Living lab” is a recently developing arena that emerged to facilitate and accelerate innovation through co-creation. (Schuurman et al., 2012) defines a living lab as “an experimentation environment in which technology is given shape in real-world contexts, and users are considered co-producers.”

Environmental sustainability and energy efficiency are areas that drive much of the building-related innovation (Femenías & Hagbert, 2013). It is evident that the housing sector extensively contributes to global environmental issues and to reduce their negative impact, there is a need for transformation not only in buildings and physical structures but also in users’ behavior and lifestyle (Femenías, 2014). Also, (Beutel et al., 2017) indicate that companies place major emphasis on users as the main indicators of success for their product development. Keeping that in mind, some theories such as Strategic Niche Management (SNM) and Multi-Level Perspective (MLP) emphasize platforms or test-beds, to demonstrate new technological innovations under a shelter, to test and verify products and services within the protective environment which is referred to as technological niche (*KTH live-In lab*). As a result, sustainable building living labs emerged as a collaborative context and a real platform to explore new ways of sustainable living and examine user interaction with technologies to accelerate innovation towards environmental sustainability transition without sacrificing human health and well-being.

After over three decades of development, the term “living lab” is associated with a wide range of meanings and research in multiple disciplines (Leminen & Westerlund, 2019). Despite this rapid growth, research on this relatively young phenomenon is still scattered (Greve et al., 2020). Academic literature has focused on numerous features ranging from definitions, key components, and trend analysis (Huang & Thomas, 2021), to exploring case-based methodologies. Nevertheless, there are still gaps in many aspects of this topic; Firstly, living labs can be implemented in a broad context ranging from cities and regions to buildings and single living areas; therefore their main actors, indicators, partners, methodologies, and concepts differ from one scale to another and there is a requirement to develop in-depth concept-based research in each context separately. Additionally, although, energy efficiency and environmental sustainability practices have been the topic of research in recent years, and announced by sustainable transition communities, it remains unclear how building living labs differ in their approaches toward environmental sustainability. Finally, the literature provides a broad picture of user activities in living labs. According to (Cui & Wu, 2016) users' activity in developing new products and services can be varied, ranging from passive participants, co-creating contributors, and design innovators. Depending on the users' role, they are involved in the co-creation process at different stages (Beutel et al., 2017). Several studies confirm the need for information on user-involvement methodologies (Huang & Thomas, 2021), details regarding user-centric tools, and the character of the living lab in practice-oriented research (Schuurman et al., 2015). While much literature focuses on user involvement methodologies at the design phase to include users at the early stage of the development process, information for experimental methods during the operation or practice stage is scarce. The importance of influential factors such as users' acceptance of the built environment and technologies, alignment between the subjective perception and the living lab objectives as well as applying various user recruitment methodologies, has not clearly been defined. All these indicators, among others, including the impact of technological innovations, and longitudinal living in a smart built environment on user's behavior and lifestyle are so integrated that it is difficult to define the effect of each factor separately. Therefore, there is a need for research on different practice-based living lab methodologies to share their knowledge with scholars and practitioners to extend their understanding of experimental activities in building living labs before they dive into it.

The thesis aims to explore building living labs around the globe to define their general trends, while the employment of the concept of environmental sustainability is the main topic of interest that will be explored in detail. Then, with a critical review and in-depth comparative case studies on the objective performance of SBLLs and implemented technologies, as well as a subjective performance by users, best practices and methodologies for user-involvement procedure and user-technology interaction, will be determined. It is worth mentioning that the purpose of the research is not to develop a new theory but to use case studies and background theories to describe a phenomenon.

To shape a framework for the thesis, three groups of research questions are defined. Each group has a main question under which several sub-RQs are categorized; by answering these sub-categories, we will be directed to the answer of the main RQ. Considering the aims and objectives of the thesis, the following research questions guide the research design:

RQ1: How the term "Building Living Lab" can be defined?

A) *What are the main concepts applied in BLLs?*
B) *How pervasive are the BLL concepts around the globe?*
C) *How has BLL developed during the evolution of the concepts of living lab?*

The first group of RQs aims at understanding the general definition of BLLs through their key indicators and defining the variety of concepts employed in BLLs.

RQ2: How environmental sustainability concept has been employed in SBLLs?

A) *What are the main indicators to define a SBLL?*
B) *In which scale and context SBLLs have been implemented?*
C) *What trend can be found in SBLLs in terms of their actors and initiators?*
D) *How do SBLLs approach towards environmental sustainability goals?*
E) *What is the level of ambitions in SBLLs toward environmental sustainability goals and how do they try to reach their goal?*

By answering the second group of RQs, the aim is to define the sustainability concept in a BLL setting by addressing challenges regarding environmental sustainability in BLLs as well as their partnership, nature of collaboration, etc.

RQ3: What are the best methodologies for effective user involvement in SBLL experiment?

A) *What are the main indicators which affect SBLL experiment results?*
B) *What is the role of each indicator in the process of living lab success?*

Finally, the third group of RQs aims to reflect on methodologies implemented in user involvement practices, including the occupancy time, nature of communication, feedback measurement tools, etc. in SBLLs, from the first step of user inclusion to the end of the experiment.

In order to provide context and elaborate on this approach, 3 chapters are provided which are based on the findings of the thesis. The first chapter outlines objectives and methodologies in more detail. This includes the procedure of approach to the goal and the areas under consideration. Chapter two tries to answer the first group of research questions by focusing on building Living labs and their main concepts. The aim of chapter three is to find an answer for the third group of research questions, regarding sustainability-oriented building living labs. Answers to the questions regarding user involvement methodologies in SBLLs can be found in chapter four. Finally, chapter five presents the main conclusion and provides suggestions for future areas of research.

The thesis has the ambition to help researchers, and living lab practitioners, gain a comprehensive understanding of BLL concepts, and SBLL approaches, as well as develop their knowledge of methodologies and procedures applied in practice-based SBLLs. It can help them to make proper decisions regarding user-centric innovation approach during experimentation phase in living lab.

01. Methodology

1-1. Research approach

The scientific process of this thesis starts by digging among previous literature to see which aspect of the living lab topic is missing or which part requires bridging the gap. This has led to framing a series of research questions so that by answering them sequentially, the main aim of the study is achieved. Besides while asking questions, some domains will be clarified such as: what we can receive from research questions or how we can benefit from the answers. Answering these questions helps us understand the way we should proceed.

The first round of literature screening starts with finding BLL cases and identifying their main concepts. After finding BLLs with environmental sustainability as their main focus, the second round of literature screening starts to extract detailed information regarding the nature of collaboration, the organization by which the living lab is initiated or funded, and the scale or context that the BLLs are implemented in, etc. At this stage, final case studies are selected for a full literature review. Further details regarding human-technology interactions and user involvement methodologies implemented in SBLL cases are extracted and all data are collected in pre-defined tables. At the end of this stage, findings should include answers to the research questions, otherwise, other methods for further data collection are considered such as survey questionnaires and interviews. Finally, after collecting findings from all stages, results are presented with the aid of qualitative and quantitative analysis and reflections. The procedure of the research approach is illustrated in a diagram with more detail in each stage in figure 1-1.

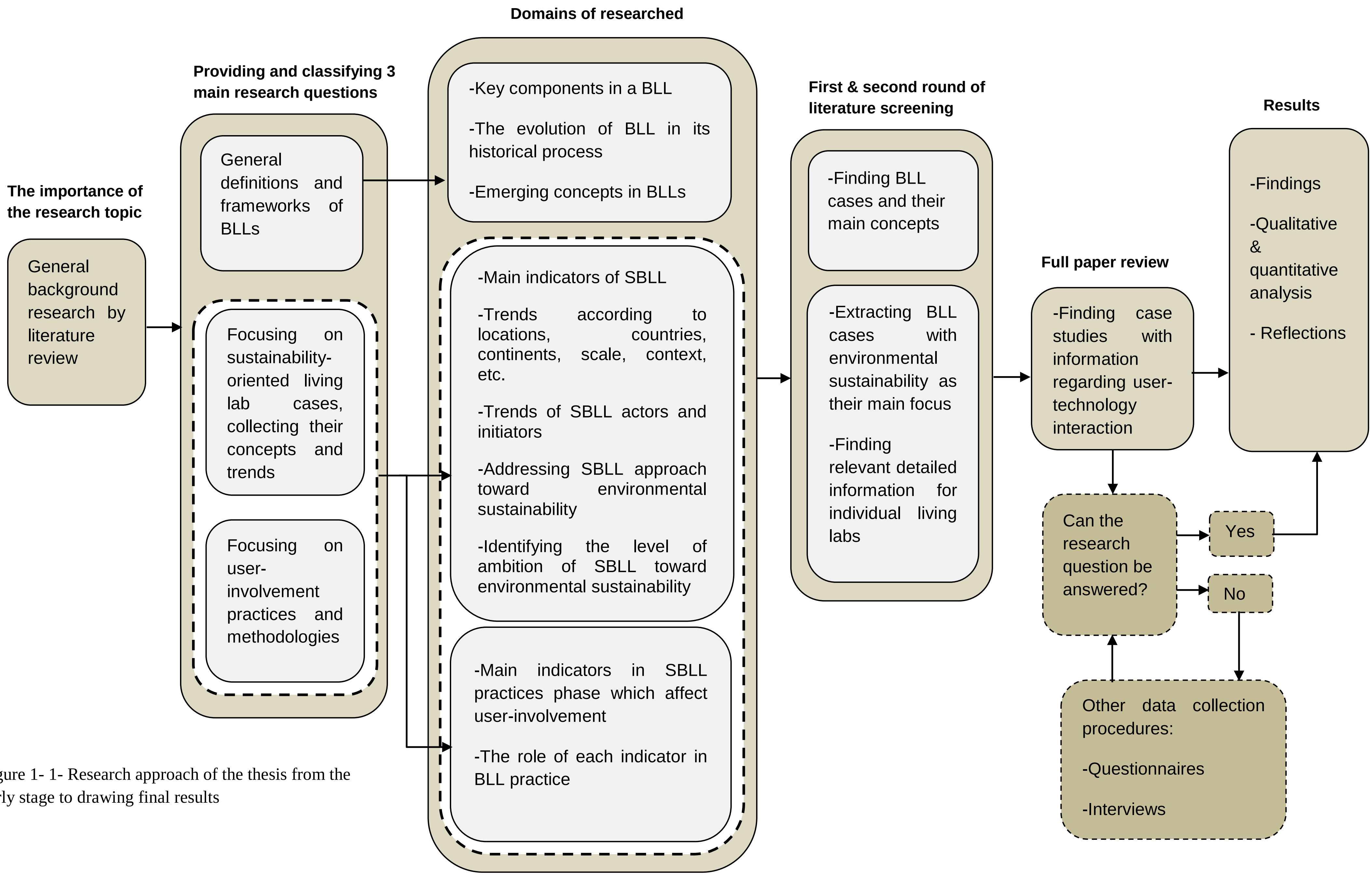

Figure 1- 1- Research approach of the thesis from the early stage to drawing final results

1-2. Methodology and the scope of the research

This study is based on a systematic literature review accompanied by qualitative and quantitative methods. The procedure of the methodology including systematic literature review and its protocols also qualitative and quantitative analysis has been provided in Figure 1-2.

A systematic literature review follows a clear protocol or plan where the criteria are clearly stated before the review is conducted, therefore they are stepwise in data collection, also, they have a particular emphasis on transparency and clarity. The main goal of the systematic literature review is to identify, refine, and organize a collection of literature and studies to find building living lab cases suitable for the scope of the thesis. The procedure has been continued step by step following these stages: 1) Data collection, 2) First round of literature screening and case finding, 3) Second round of literature screening and data gathering, and 4) Full paper review of selected case studies and questionnaire. After selecting research sites and sampling respondents, a mixture of qualitative and quantitative questions in the form of questionnaire has been sent to the responsible person of living labs. Finally, through quantitative and qualitative analyses of findings from literature review, case studies and questionnaires, final results would be available.

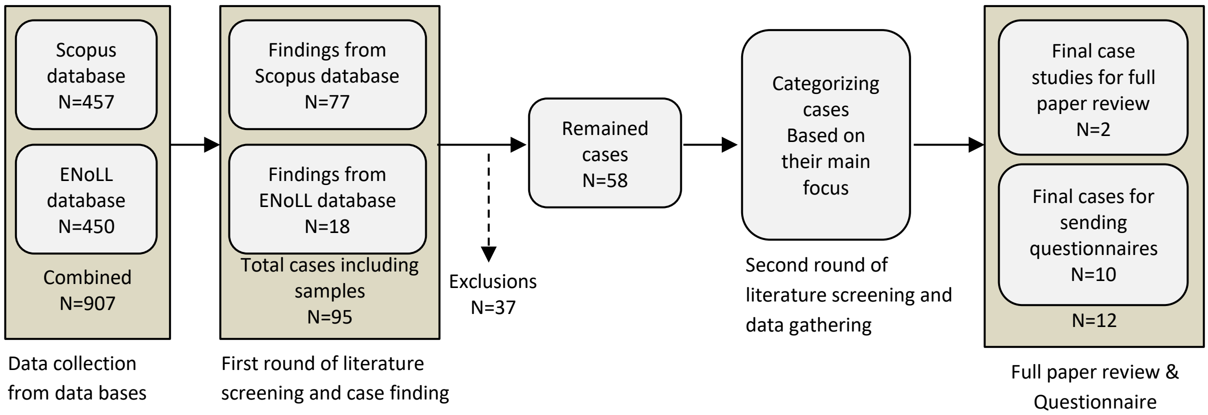

Figure 1- 2- The methodology of data collection in a systematic literature review

Number of exclusions	Exclusion protocol	Description
12	Duplicates	Including living labs available both in ENoLL and Scopus database
1	Not constructed	Including living labs which the aim is to be constructed in the future
3	No information found related to constructed living lab	Including living labs that must be built years ago, but no information is available regarding the constructed building. So, we are not sure now if it is built or not.
7	Not enough information	Including cases where the information regarding the building is rare.
14	Without any name or brand	Including buildings in which a type of technological experiment has been used in them once and the name of the building is unknown.

Table 1- 1- Exclusion criteria during data collection process

1-1.1. Data collection from databases

The purpose of data collection is to find case studies within the research scope of the thesis which is a "living lab" implemented in a "building" as a "real-world context". Therefore, other living labs that are not empirical or are based on virtual reality or digital sense, as well as laboratories which are not applied in a building context are excluded; this includes other living lab scales such as city, region, and rural living labs. The research expanded to all cases available around the world, from 1990 to 2021, to have a holistic view of this type of living lab. It has been conducted through an online investigation among English literature to eliminate any misunderstanding in communication through translation.

As the main source, data collection started among available cases in ENOLL (European Network of Living Labs), which is popular as the most comprehensive living lab database (Veeckman et al., 2013). Taking a glance at the ENoLL webpage makes it clear that although it has a search engine, it is not possible to define a particular concept of living lab even among active cases. The reason might be the lack of data available among some of the living labs in the database; also, the search engine was not practical for our specific research topic. Since the subject is "building" as a living lab, there was no possibility to separate buildings from other contexts or scales of living lab activities. Due to this limitation, searching requires individual investigation among all living labs including active or inactive cases. After finishing one by one case research in ENoLL, it becomes clear that the number of building living labs which can be found in this database is quite low. Therefore, Scopus was added as the second source of database.

Research in Scopus has been conducted by a series of keywords extracted from the description of our living lab concept. The word “building living lab” was searched in combination with a variety of other words, including “living laboratory”, “campus lab”, “university building living lab”, “habitation lab”, “home living lab”, “sustainable living lab”, “suslab”. Also, “real world context”, “real”, and “experimental” are included. Other words which excluded are “clinic”, “animal experiment”, “medical experiment”, “labor”, “digital”, “methodological”, and “virtual reality”. In this way, 457 documents are found by the research engine.

1-1.2. First round of literature screening and case finding

This round of literature screening is to determine cases which should be included in further stages of the research. The screening has been conducted by exclusion criteria with the inclusion of “building living lab”. It can also be considered as a critical step in the process of systematic literature review.

Among all 450 cases in ENoLL database, 18 cases have been found inside the research scope, regardless of being active or inactive. This procedure took place from 2nd-15th February 2022 and no attempt was made to contact any of the living labs during this period. Also, from 457 literature in the Scopus database, 77 living lab cases are considered for further review. This number also includes the samples in the literature. 16th February till 5th March 2022 was the time allocated to this stage.

Meanwhile, all the information regarding the living lab name, year of construction, location (country), main concept or thematic focus, and the objective performance, defined in the living lab description, is organized in a particular table.

1-1.3. Second round of literature screening and data gathering

This round of literature review includes exclusion criteria provided in Table 1-1. All remaining BLLs from this stage would be categorized according to their main concept. Therefore, detailed information regarding individual living labs is gathered in a particular table dedicated to each living lab case. This table is used as the living lab identity and classified into four main categories illustrated in Table 1-2. The original table is available in Appendix 1.

Categories	Category description
Lab ID	Identified information related to individual living lab
Lab features	Information regarding the objective performance of the living lab and how it is recognized as a living laboratory
Type of partnership	Information regarding the collaborative arrangement of the living lab
Sustainability approach	Describing the living lab approach toward environmental sustainability

Table 1- 2- Categorizing individual living lab identity

1-1.4. Full paper review of selected case studies

This is the final step of data collection from the literature review. It facilitates collecting qualitative data from available information in literature. In this process, qualitative data from multiple empirical cases would be collected and analyzed in different categories. Case studies were selected among SBLLs according to

As (Bryman, 2011) suggested the case study approach is suitable when the research is answering to "why" and "how" questions and the answer requires a comprehensive explanation.

1-1.5. Questionnaire

During the literature review, it has found that there is lack of data in many aspects of BLLs. Therefore, a survey questionnaire is designed to fill in these gaps. Since this step is a complimentary for the literature review, the research was highly selective to pick cases with particular focus of human-technology interaction. 10 cases were selected to be included in the survey. It is important to note that 2 BLLs used in full paper review are not included among these 10 selected cases.

The survey has been sent out online via e-mail to the contact e-mail addresses found for each BLL. The first round of sending the questionnaire was on the 25th of April. The first 2 answers were received on 28th April and 3rd of May confirming that they have answered the survey. Due to the limitation of time for the submission deadline of the thesis, the second effort was made on the 11th of May by resending the survey to the one who did not respond. 2 more answers were received on the 12th and 13th of May, however, it was not answers to the survey. One of them redirect the email to the responsible person of the BLL, and the other said that they cannot answer it because their aim of use is different. Despite one more attempt on the 23rd of May, no answers were received afterward.

1-1.6. Quantitative and qualitative analysis and reflections

Quantitative information is used to answer the first and second groups of research questions. Extracted data would be illustrated in a comparative form such as numbers, percentages, charts, and diagrams, while qualitative analysis aims at answering the third group of research questions and they are presented in the form of findings and reflections.

02. Building Living labs and their main concepts

This chapter deals with the goal of first group of research questions. It will investigate the BLL from a variety of applied concepts while exploring the emergence and development of this phenomenon by exploring cases found in the literature.

It begins with a brief introduction to LLs and their emergence. Some relevant definitions have been used for this purpose. The idea is to provide an implicit understanding of the term "BLL" which is the main focus of the research.

The chapter will continue with a section regarding the history of BLL, its scales and contexts. It provides some data regarding the classification of the buildings in terms of their situation and context. In addition, by providing information on the building situation, the aim is to find out the number of buildings which has been built to act particularly as a test-bed for LL purpose. By exploring the contexts, it is tried to understand the most popular building types used for this purpose. BLLs are categorized into 3 main concepts based on the experiment running in the building. You will find detailed information related to each concept at the end of this chapter. The section will finish with a brief history of the development of BLLs. Talking about the history is not merely based on some data gathering from already written background information that can be found in literature; instead, it is a timeline of the most important ideas that happened during the development and transformation of the BLL concept, from the author's perspective.

The chapter will be closed by introducing 3 main concepts of BLLs. Except for the first concept, the other 2 will be explained in more detail including the name and descriptions of the cases. The first, however, will be the subject of a full discussion in the next chapter.

2-1 Building living lab definition

In order to have an implicit understanding of the building living lab definition, one should first, realize the components and its important features. Since there is no definition, particularly for building living lab, the idea is to identify LL description applied in a building as a real-world context. The purpose of this section is to provide an understanding of the term BLL which this study focuses on.

Since its inception, many definitions have been offered in the literature to implement the concept of LL. It has been used as an environment, a methodology or innovation approach, an organization, a network, or a system (Curtis, 2015). It would be difficult to find the first roots of Living lab, since before 1990 the usage of this term was scarce. Most literature introduces Professor William J. Mitchell of the Massachusetts Institute of Technology (MIT) as the pioneer and "the Grandfather of living labs" (Leminen & Westerlund, 2019). In 2006, when European Networks of Living Labs (ENoLL) took form, LL practices officially start to take off in Europe. After that, more support was given to LL projects in Europe and elsewhere. During this time, LL has been defined by numerous scholars; however, no generally accepted definition encompasses all factors, actors, and activities among LLs.

The original idea of LL as a test environment, such as a building or a set of buildings, replicating a home has evolved since 2000. This means that even from the beginning of the emergence of LLs, the need for a context to test and prototype services, materials, and technologies was understood. The first generation of LL of this type was conducted in a home-like environment with facilities to support temporary residents for prototyping and validation of ICT solutions. Later, the concept has been evolved into user-centric open innovation approach (Ståhlbröst, 2008). Among 18 different definitions found by (Compagnucci et al., 2021), 3 of them identify LL as "an experimentation environment" (Ballon et al., 2005; Schaffers & Kulkki; Westerlund & Leminen, 2011), and 3 studies describe LLs as "intermediates" for open innovation (Almirall & Wareham, 2011; Ståhlbröst, 2008; Ståhlbröst & Bergvall-Kåreborn, 2011). ENoLL also describes LLs as "intermediaries" between different actors to scale up innovation (Compagnucci et al., 2021). Apart from that, some theories such as Strategic Niche Management (SNM) and Multi-Level Perspective (MLP) which both discuss innovation and technology shifts emphasize the importance of test-beds referred to as "technological niches". This is a protected environment in which technologies can be tested and verified with a higher level of interaction among various actors (*KTH live-In lab*).

According to some of the definitions for the LL (Pallot & Pawar, 2012; Westerlund & Leminen, 2011), the nature of collaboration in LL activities can be described as "4Ps" as public-private-people-partnership"; these 4Ps are usually referred to as industry, government, and academia which enable users to actively take part in the projects. Each of these four actors is the basis of activities driven by different LLs: 1) Utilizer driven LLs, which are managed by companies, 2) Enabler-driven LLs, which are projects running mostly by the government, 3) Provider-driven LLs, running by scientific institutions or universities, 4) User-driven LLs established by the community of users (Leminen et al., 2012). However, until these recent years, users were not included among the main 4 actors of LL activities; although, research on user innovation dates back to four decades ago (Beutel et al., 2017). Before that, users were only passive subjects who were under observation during the LL experiments. User empowerment took place after the development of ICT and the need for fundamental transformations in this industry. Major attention has been given to users, since the success of these companies is highly related to the level of users' satisfaction with the products and the extent of technology acceptance in users' daily life. Therefore human-technology interaction has become one of the most important studies conducted in LL environments. Hence, our definition of the building living lab is not a mere context to test materials and services; instead, it is more in line with the definition of (Andersson & Rahe, 2017) which identifies LL as "a research platform that aims to optimize the interface between human behavior and technology systems in a real-life environment." This context can be either a building furnished as a home for temporary residency to study human-technology interaction, or a public building such as university facility to implement new technologies to be studied in a real-life context. These controlled and protected environments might be initiated by companies, scientific or educational organizations, or the public sector.

The next section will describe the author's findings from cases found in literature regarding the variety of BLL concepts which are applied in different contexts around the globe.

2-2 The history of the emergence of BLLs concepts and their implemented contexts

After an investigation in ENoLL and Scopus databases to find relevant BLLs around the globe, final refinement was done based on predefined protocols. 58 living labs are left for further analysis. The research shows that BLLs are implemented in a variety of contexts ranging from single living spaces to public buildings with multiple activities. The classification of the contexts is based on the BLL purpose or its usability which is provided as follows:

1) Single area: this includes a living space with a few square meters area, furnished to be used as a living space. An example of this kind is Studio Home in the ID Studio Lab of the Delft University of Technology which is a large room turned into a living room to conduct research projects on interactive home products (Pasman et al., 2005).

2) Single family house: it can be described as a living space for members of a single family with all required areas such as living room, dining room, kitchen, bedrooms, bathroom, etc. The area can be varied from 40 m^2 (The LOW3 prototype Solar House) to 690 m^2 (Toyota dream house). It can be a single-family detached house or a single-family apartment in a building.

3) Public building: it can be identified as multi-story structures such as educational facilities, office buildings, or residential facilities in the form of dormitories. Cases in this category are varied in a wide range of scales, from 2000 to 30000 m^2 area.

4) Mixed-used facilities: this category of BLLs is a combination of different activities, in addition to a house as a test-bed. Including office area, showroom, research facility, etc. Drexel Smart House and universal design living lab are examples of this category.

5) Infrastructure: this category consists of LLs with a structure which provides a highly flexible setting, particularly for environmental sustainability research. NEST can be a perfect example of this type.

Apart from this, the research has found that not all buildings are new to be used as a living lab context. They can be refurbishment of a previously constructed building or a simulated space for research. Meanwhile there are some cases that their situations have not been identified. They are labeled as “unknown” in this study. Figure 2-1 provides an overview of the context and situation of BLLs. While the majority (33 cases) of research regarding BBLs takes place in single family house contexts, most of them (24 cases) are newly built. This shows the popularity of single family houses to be used as a test-bed in LL experiments.

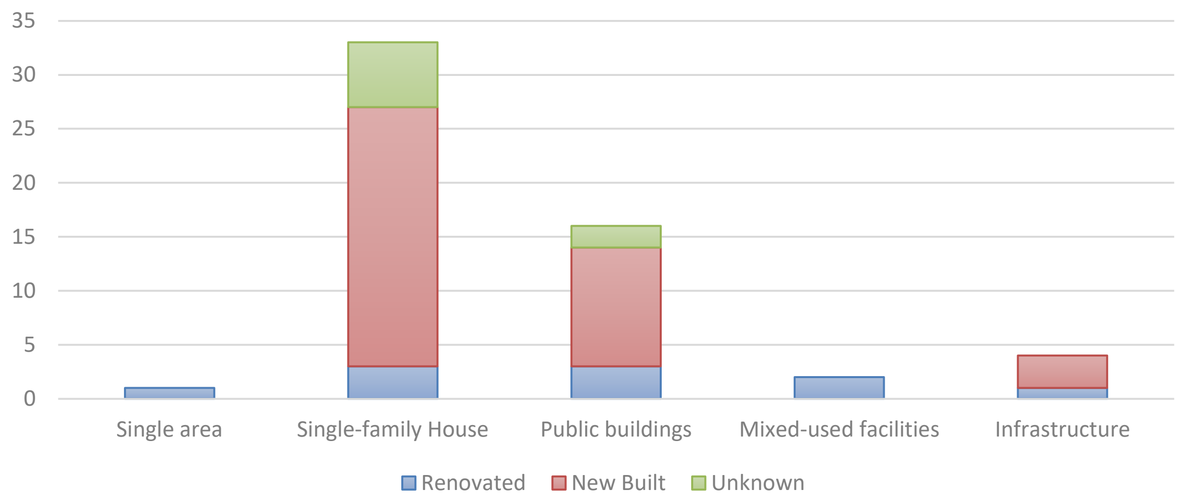

Figure 2- 1- The distribution of BLLs in different contexts

An overview of the distribution of living labs around the globe makes it clear that they are divided in 21 different countries, situated in 4 continents. Despite this diversity, 64% (36) of BLLs are located in Europe, among which, 16 BLLs situated in only 3 countries of Germany, Italy, and France. While 25% (14) of all BLLs are in North America, U.S. has the majority of BLLs among all countries with 10 cases. Only 11% of BLLs are located outside the Europe and North America. Asia includes 5 cases (9%) and Australia only 1 (2%). Figure 2-2 and 2-4 provide an overview of the distribution of BLLs based on countries and continents.

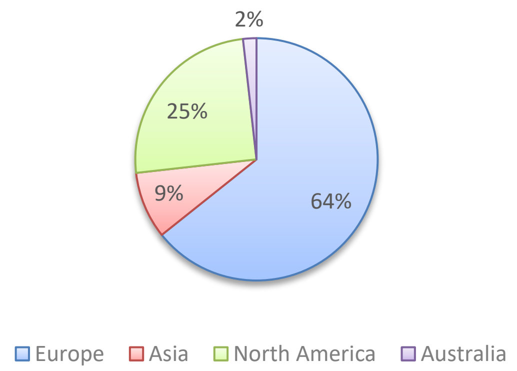

Figure 2- 2- Percentage of the distribution of BLLs based on continents

Thematically, these laboratories are divided according to their main concepts into 3 main categories (Figure 2-3) which will be more clarified at the end of this chapter. These 3 concepts are:

1) Environmental sustainability, 2) Ambient assisted living, and 3) Educational purpose

These concepts are elaborated according to the descriptions available in literature regarding the objective performance of each BLL case. Environmental sustainability includes 29 BLLs, ambient assisted living consists of 25 cases, and educational purpose is the objective performance of only 3 BLLs. Since some of the BLL projects have dual purposes, the classification and distribution of cases are based on the main objectives of the BLL activities.

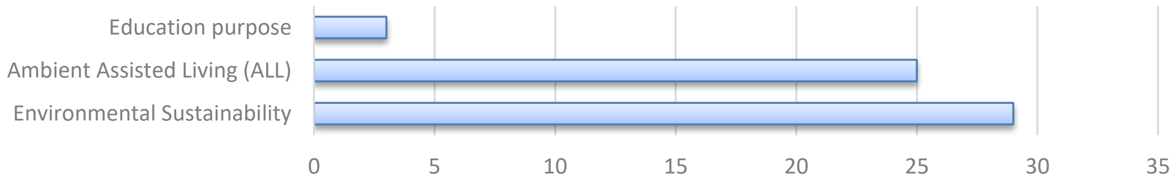

Figure 2- 3- Distribution of concepts among BLLs

By looking at the division of these concepts globally, it has found that the first two concepts (environmental sustainability and ambient assisted living) have evenly distributed among different countries relatively; however, the latter has been the topic of interest in Germany and the U.S. Although BLLs with educational purpose is available in some countries, projects with this objective have been only found in North America (Canada and the U.S.). Figure 2-4 presents the distribution of BLLs among countries based on their focus of activities.

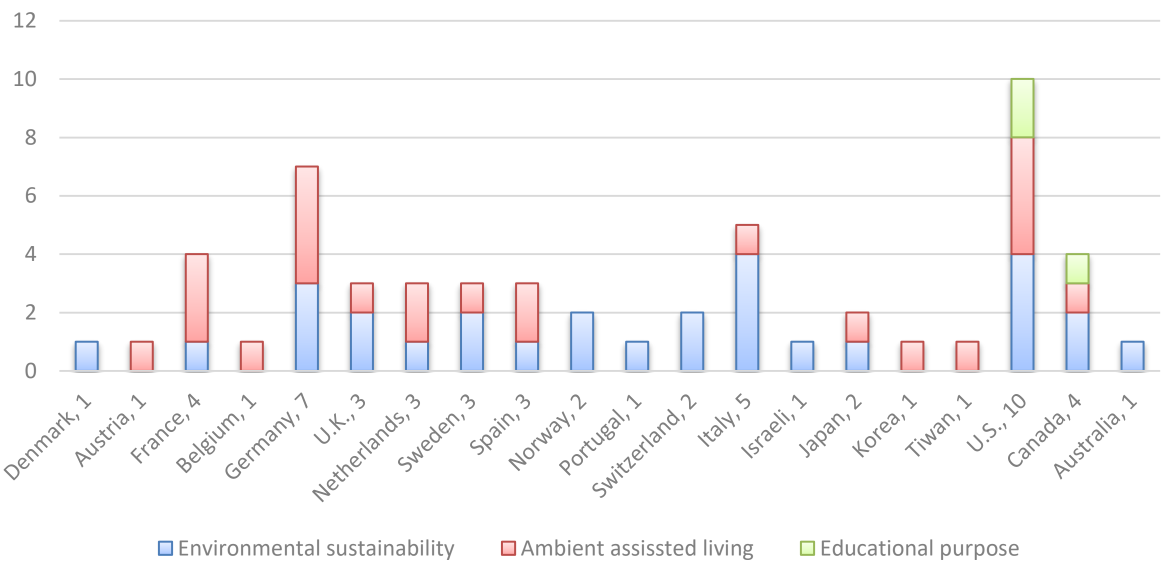

Figure 2- 4- The distribution of BLL concepts provided based on countries

This section is following by a brief history of major findings regarding BLL concepts. Figure 2-5 illustrates the distribution of BLLs according to their construction date. Among 58 cases under study, 6 LLs where their construction date was unknown, are not included particularly in this diagram. The figure apparently shows that the number of BLLs has been increasing dramatically, in recent years, and this is while the research objective of environmental sustainability is growing.

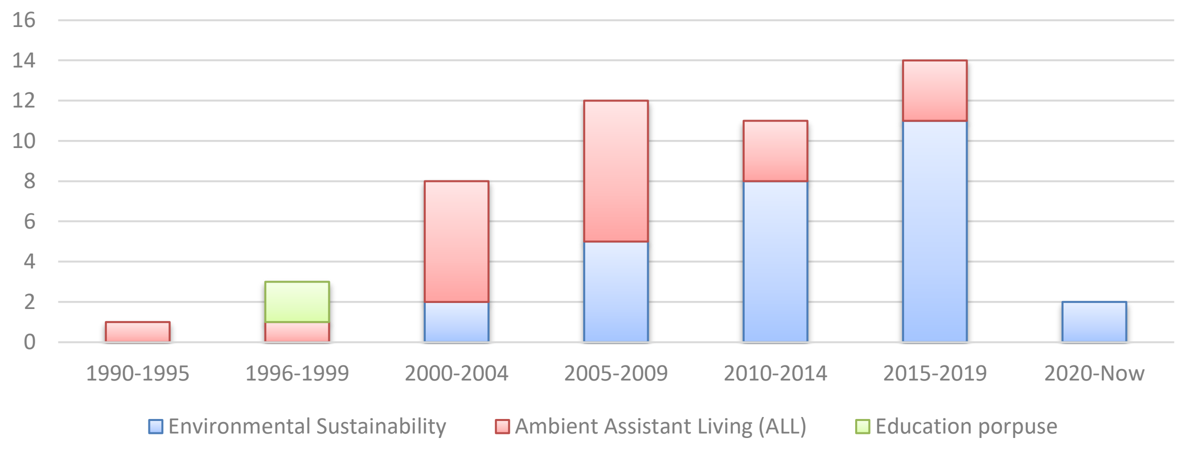

Figure 2- 5-Distribution of BLLs concept

From 1990 to 1999, only 4 BLLs were built. Their main concepts were Education and AAL. These LLs are situated in 3 countries of Italy, France, and U.S. where can be considered as the pioneers in these two concepts. The oldest BLL was built in 1995 in Italy with the focus on active and healthy aging in smart environment with ICT and advanced robotics (Esposito et al., 2016).

There were no BLLs with environmental sustainability practices among cases prior to 2000. Efforts on this concept begin in 2001 with 2 cases in Germany and Switzerland. The former is a newly built single family detached house initiated by Fraunhofer Institute for Microelectronic Circuits and Systems and the latter is a university facility renovated with the focus on optimizing ICT and BEMS to enhance energy efficiency. These two cases are pioneers in environmental sustainability building living labs which both have particular interest in employing ICT to control and monitor energy consumption in the building. However, in the Fraunhofer-inHaus 1 project, the focus was not only on environmental sustainability, but AAL concept was also included. Other BLLs with more than one concept are also available during the history of BLLs. Examples of this are BLLs which has been built for Solar Decathlon competition. The aim of the competition is to develop innovative ideas for designing high performance, low carbon buildings powered by renewables while trying to reinforce students' capabilities with hands-on experience simultaneously. Only 3 projects of Solar Decathlon competition constructed in 2007, 2009, and 2011, were among cases found in literature. These buildings were deconstructed and rebuilt at the university campus after finishing the competition to act as a test-bed for further environmentally friendly projects.

First prototype of single-family BLLs with environmental sustainability as their only objective is traced back to 2012 with a national project of Efficiency-House-Plus network in Germany. This project considers all aspects of environmental sustainability such as indoor environmental quality, energy efficiency, material circularity, and the use of renewable energies. Educational concept in BLL cases, however, has been found in 1996 and 1997 in U.S. Although, LLs with education as their primary focus is rare, many cases have been built to train students while their main aim is to be an environmentally friendly building or to test new technological innovations. The name of related projects is available in Table 3-3 in chapter 4.

One important aspect of living labs is the capability for replacement and modifications of systems and components. In 2016 a new generation of BLLs was emerged with the NEST (Next Evolution in Sustainable Building) project in Switzerland. These types of BLLs are basically infrastructures which are used as a test-bed with extensive flexibility for testing new technologies in the building context. Prior NEST, however, there have been other projects such as Solar XXI building living lab in Portugal built in 2006 where the possibility of adding or removing solar panels to/from the exterior walls was provided. But these two projects have a major difference; in Solar XXI, the BLL itself has a function acting as an office building, although the building has been constructed with flexibility to be used as a text-bed; while NEST only responsible to act as an open platform for testing materials and services. KTH Live-in-Lab (LiL) in Sweden, and CNR-ITC ZEB Laboratory in Italy, built in 2017 and 2019 respectively were BLLs with the similar purpose.

Around 2016, by realizing the importance of social science on peoples' environmentally friendly behavior, the role of shared places in residential facilities became prominent. Therefore we have witnessed the emergence of BLLs which aim at researching the impact of shared facilities and social living on reducing energy consumption and carbon footprint. HSB living lab in Sweden is the first prototype of this kind. KTH LiL has also undertaken similar projects in recent years to examine various aspects of social life in terms of energy saving in households.

In general, although the emergence of BLLs was taken place in 1995, practicing environmental sustainability in BLLs appeared several years later. While the number of SBLLs has been increasing since its inception, new generations of LLs appear to make this phenomenon more practical for different researchers. We have to wait to see which new aspects of BLLs will emerge in the near future. Figure 2-6- describes the timeline of focal points found during the development of BLLs.

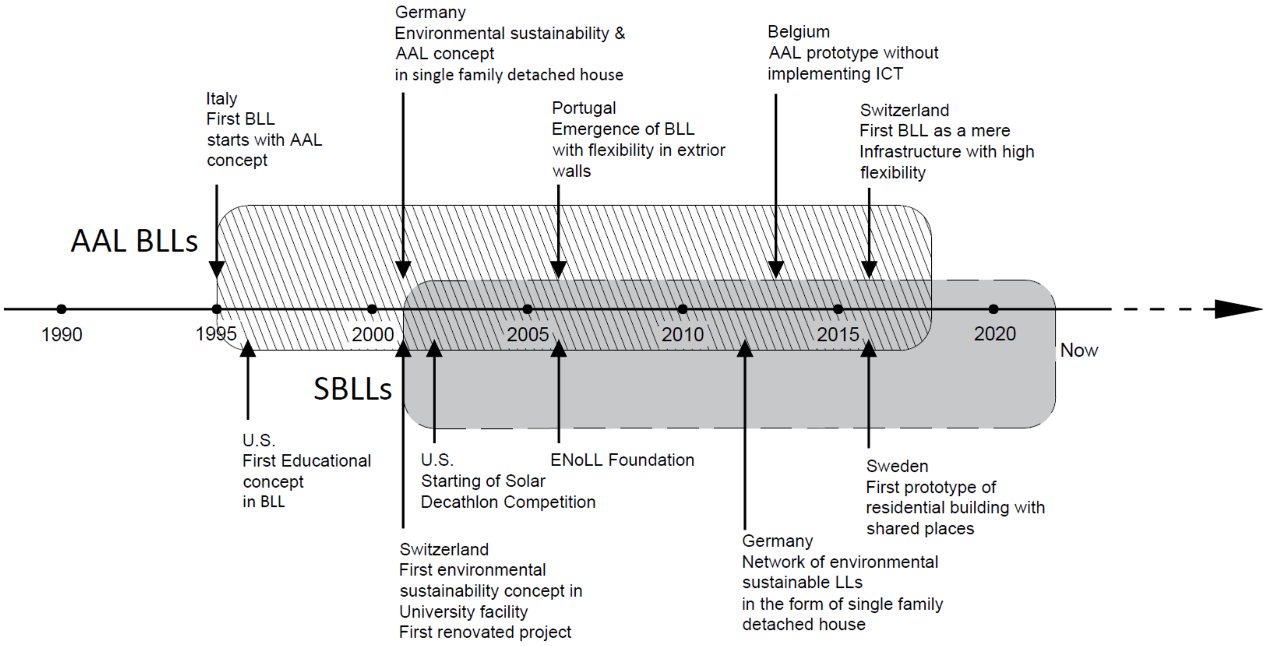

Figure 2- 6- The timeline of the development of BLLs

2-2.1 Environmental sustainability

As mentioned previously, Environmental sustainability has been the concept of most BLL cases. Projects with this concept will be explained in more detail during the next chapter. Therefore, this section only provides an overview of the number of cases and their association with the sustainability concept.

Among 29 cases which communicate environmental sustainability as their objective, 9 cases were built only to act as a test-bed to examine human-technology interactions. 11 cases have additional concepts apart from sustainability, among which 3 cases follow AAL concept, and

8 cases indicates educational purpose as their secondary aim. The remaining projects categorized in public buildings are labeled as LL while they already have a function; this means that the building is designed for a particular purpose apart from being only a testing ground for technologies. In this type of BLLs, the role of users is completely different from others, since they have different approaches toward sustainability practices. These projects are mostly designed based on ICT or BEMS to control and monitor IEQ as well as energy balance. Name and description of BLLs with this concept is available in an online repository[1].

2-2.2 Ambient assisted living (AAL)

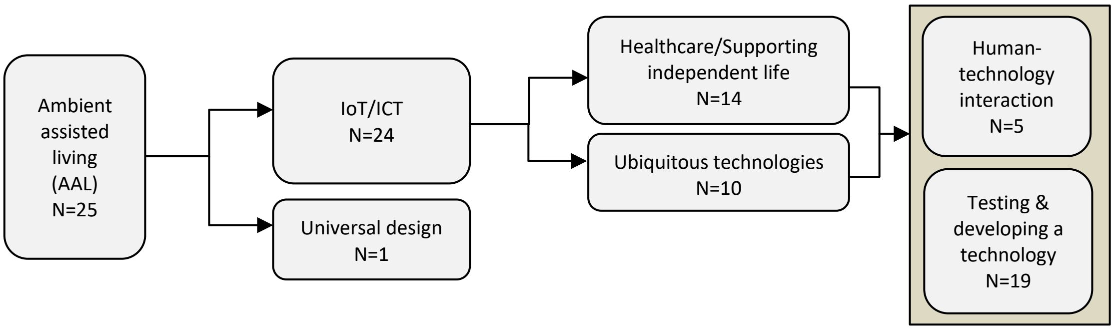

Figure 2- 7-The dispersion diversity of the concepts of AAL among BBLs

As mentioned before 25 living lab cases have defined their objective performance as ambient assisted living or one of the related subjects. You can find the name and description of each BLL with this concept in an online repository[2].

There is no single description of AAL, and it is mostly defined as life assistive technologies in the form of products and services which help vulnerable people in their daily routine activities by increasing their independence and improving their quality of life. To reach this aim, Information and Communication Technologies (ICT), Internet of things, intelligent systems, cameras, sensors, and etc are being employed in buildings. BLLs that incorporate such technological innovations are called Smart BLLs which is identified as "human-centered smart life environment that promotes the welfare and safety of residents by converging IT into residential environment" (Seo et al., 2021) .

The division of the role of ICT in smart BLLs falls into 2 different categories including: 1) healthcare/ supporting independent living, and 2) ubiquitous technologies. The first is trying

[1] https://doi.org/10.5281/zenodo.6596348
[2] https://doi.org/10.5281/zenodo.6596340

to develop products and services to enhance the quality of life for elderly, vulnerable, and disabled people by facilitating their daily activities and helping them in emergencies by contacting relatives or healthcare centers. While the second aims at context-aware technologies including home security, remote control systems for the interior environment, energy conservation, and monitoring. It is difficult to separate these concepts from one another, since the aim of both is to facilitate humans' life; Yet, according to the main objectives of BLLs provided in their definitions, 11 cases focus on Ubiquitous technologies, while 14 living labs have healthcare and independent living as their primary concept. Figure 2-7 illustrates the diversity of AAL concepts found among BLLs.

One of the main studies conducted in smart BLLs is behavioral research. It explores human's behavior in smart living environments, technology acceptance by users, and the usability of the technology in a real-life context. Since there is little data on feasibility and utilization of technology in buildings, there is a need to receive residents' feedback for further technological developments in the future (Seo et al., 2021). It is found that only 5 BLLs have defined their objective as an interaction between human, technology, and the environment. Among those, Philips Home Lab in the Netherlands is the only project which describes its research activities as human behavior in smart environments, technology acceptance, and human-technology interaction (Ruyter et al., 2005). Although human-technology behavior has been the subject of research in many of the BLLs within AAL concept, they mostly try to test and develop new products and services by user involvement methodologies rather than observing this mutual interaction.

Only 2 living labs (The Home Aware at Georgian institute of technology and the Place lab at MIT) describe their objectives as multi-dimensional research activities: MIT Place Lab focuses on context-aware ubiquitous computing technology, preventive healthcare, energy conservation, and education (Intille et al., 2005). The Home Aware living lab defines its main research areas on health and well-being, digital media and entertainment, as well as sustainability (*The Aware Home Research Initiative*).

Exploring the concept of AAL in BLLs, elaborate on the fact that there are other efforts in this domain which is not solely based on ICT; instead, they are aiming at adaptable living and comfort in a physical environment to support people's independent living, regardless of using intelligent systems. One living lab –universal design (UD) living lab in Belgium- focuses on attractive and elegant environmental design solutions (Herssens et al., 2014).

2-2.3 Educational porpuse

Education particularly in building engineering has been transformed from traditional teacher-based classrooms to new learner-based experience that actively invites students to engage with "real-world" materials and technologies (O'Brien et al., 2021). Living labs with their particular properties in a real-world context can provide a perfect platform for both learning and research. A great number of BLLs found in literature have dual purposes. While their primary aim is to act as an environmentally friendly building, they try to provide an experimental context for students to enhance their hands-on capabilities. Meanwhile, some buildings describe their activities merely as an educational context. These types of BLLs are occupied buildings (mostly in the form of university facilities) where building technologies and their occupants are under study. Since building performance science is not merely studying energy generation or energy saving strategies, instead, ir requires real buildings occupied by real users to understand the impact of these two components on each another. These types of facilities have to be designed and built up from the beginning for 4 main purposes; They have to be constructed for exposure, measurement, manipulation, and documentation (Carlson & Brandemuehl, 1997); meaning that they must illustrate various engineering systems, they must provide students with the possibility of real-time monitoring of energy and IEQ situations, they have to make students capable to control building environment in order to compare various scenarios, and finally, they should provide students with detailed construction process of the building with videos, BIM software, and simulated calculations. Table 2-1 consists of the name and description of BLLs found in literature with their main aim related to the Educational concept.

Living lab name	Objective performance	Description of the lab	Source
The Peter Kiewit Institute (PKI)	Education: Teaching and learning Engineering science	The building was designed to be a living laboratory. Nearly all the building systems are exposed to allow students and faculty the opportunity to continue learning even after classes have ended.	(Alahmad et al., 2007)
Integrated Teaching and Learning (ITL) Laboratory	Education: Teaching and learning Engineering science	It is a university facility designed to facilitate hands-on team-oriented learning across all of its six departments at the college of Engineering and Applied Science Colorado.	(Carlson & Brandemuehl, 1997)
Carleton University	Engineering education, Experiential learning	No description available	(O'Brien et al., 2021)

Table 2- 1- Name and description of BLLs with educational concept

2-3. Lessons learned

This chapter tried to find an answer to the first group of research questions:

RQ1: How the term "Building Living Lab" can be defined?

A) What are the main concepts applied in BLLs?

B) How pervasive are the BLL concepts around the globe?

C) How has BLL developed during the evolution of the concepts of living lab?

First, it started with a brief description of key indicators applied in the definition of LLs. It has been found that the term "living lab" covers a wide variety of domains and even from the emergence of its first definitions the necessity of a context for testing new prototypes has been identified. However, No particular definition has been found for BLL in literature, and the role of users as active co-creators has been defined only in recent years.

To find answers to sub-research questions, the study tries to explore among case studies to define a trend among activities in BLLs.

A) According to their usability purposes, this study has identified BLL activities in 5 various contexts: Single areas, single family houses, public buildings, mixed-used facilities, and infrastructures; while the situation of the buildings to act as a BLL are different. They can be newly built constructions or refurbishment facilities. Findings from literature screening illustrated the fact that BLLs provide their activities based on 3 main concepts. They can be categorized as: environmental sustainability, ambient assisted living, and educational purpose. According to their primary purposes, environmental sustainability comprises the majority of BLL concepts.

B) The distribution of these 3 concepts among various countries shows that 2 concepts of environmental sustainability and AAL, comprise the majority of BLLs in European countries. Among all countries, the U.S. which is the pioneer in LL activities has the largest number of BLLs with all 3 concepts. In Asia, only 2 countries illustrate environmentally friendly activities in BLLs. And Australia with only one case has started relative actives in recent years. In general major interest has been devoted to BLL phenomenon in recent years. And among 3 main concepts, environmental sustainability has taken the lead after 2010.

C) The evolution of BLL starts with the emergence of 2 main concepts of AAL and education. Environmental sustainability emerged later around 2001; however, the case had AAL as its second concept. At the same time, in a larger scale building context, environmental sustainability had been in practice in a renovated educational facility. The emergence of the Solar Decathlon competition had a great influence on evolving BLLs in the form of single-family houses with the objective of environmental sustainability, while providing practical educational values for students. Yet, the first prototype of a single family BLL which included all aspects of environmental sustainability activities, built later in 2012. In 2016, BLL facility evolved from a building to a mere infrastructure with maximum flexibility. In the same year, social science has entered into BLL activities where we can find new generations of BLL in multi-residential facilities.

Finally, to define an answer to the main research question, this study defines BLL as "a research facility applied in the form of a real building context, in which different main actors (e.g., companies, government, scientific institutions, and users) co-create together for testing and developing new prototypes. It can have one or several concepts for its activities. It can be a physical space with variable settings, a building with a particular function (e.g. full-scale office building), or a test-bed ranging from a particular building to a mere infrastructure with maximum flexibility for implementing and replacing technologies."

03. Conceptualizing environmental sustainability-oriented building living labs

This chapter will focus on building living labs with sustainability as their main concept. The aim is to provide an overview of SBLLs with their trends and main indicators. The first effort is to provide a comprehensive definition regarding SBLL and its main determinant factors. For this reason, we will start discussing sustainable development and its different dimensions. Then, by providing a quick comparison between the term "green" and "sustainable", we will explain the reason why we prefer to choose to be "sustainable" rather than "green" for building living lab. Finally, we will add the indicators of the sustainable buildings to the definition of sustainability living lab to provide an identity for SBLLs we are focusing on in this research. After finishing this part, the research will start digging among relevant case studies to have an overview of the distribution of SBLLs among countries and continents. Also to understand their context, scale of action, initiators, and relationship between a variety of actors, as well as defining their major trends towards environmental sustainability. This includes their approaches toward environmentally friendly practices by searching among implemented technologies in the buildings. Therefore, the information in this chapter is organized as follows: 1) The definition of sustainable building living lab, 2) Geographical distribution, 3) Functional scale or context of application, 4) Domain of activities or schematic focus regarding environmental sustainability, 5) Nature of collaboration among actors and stakeholders, and 6) Their lead actors or initiators. At the end of this chapter, there will be a discussion on SBLLs with secondary goals. Finally, we will talk about additional findings regarding other environmental sustainability aspects in projects.

3-1 The definition of the sustainable building living lab

In order to provide a description of a sustainable building living lab which is the main topic of this chapter, we should clarify some terms and definitions underlying this concept. While the goal of sustainable development is the foundation of all sustainability activities, we will start with this concept to realize how the concept has been understood and which of its variety of aspects are more accepted.

3-1.1 The definition of sustainable development and the aim of sustainability in buildings

The most famous definition of sustainable development was provided by Bruntland Commission (WCED, 1987) which is explained as “a development which meets the needs of the present without compromising the ability of future generations to meet their own needs.” After Bruntland, sustainable development has been identified in a diversity of definitions which represents the point of strength of this concept (Berardi, 2013). An overview of different descriptions demonstrates the variety of domains into which sustainability concept can be divided. Environmental, social, and economic aspects are dimensions of the sustainable development which were previously defined in Bruntland Commission (WCED, 1987). In recent years two other aspects of sustainability including cultural and political have also been added to previous dimensions.

Despite all different domains, since sustainability concept is more understandable by practical measures, the definition is often considered in terms of environmental perspective while excludes other aspects of sustainability (Hugé et al., 2013).

3-1.2 The definition of Sustainable Building (SB)

Sustainable development in the building has received major attention so far on the global scale, and the reason has been the undeniable role of the building sector in an excessive amount of energy consumption and an increasing quantity of GHG emissions which account for 30% and 40% in developed countries respectively (Berardi, 2013). Meanwhile, some studies proved that the energy consumption in housing is much higher than the other sectors and the rate of energy demand in buildings is increasing substantially (Akashi & Hanaoka, 2012). An overview of the data in construction sector shows the growing rate of construction in buildings and the increasing demand for new houses in both developing and developed countries (Industry, 2003). All these facts call for increasing demand for sustainable buildings to achieve the goals of sustainable development. Thus, the importance of the term “environmentally sustainable building” among other sustainable development policies is clear to a great extent.

Meanwhile, a question arises: Why do we choose the term “sustainable” over “green” or why do we prefer to have “sustainable buildings” rather than mere “green” ones? By looking at their definition, the distinction between two terms of “green” and “sustainable” would become clear. “Green buildings” tend to emphasize designs that consider the usefulness of applying renewable energies and reducing consumption as well as treatment of waste. “Sustainable buildings”, however, aim at balancing all dimensions of environmental sustainability in a long-term process to be maintained for future generations (Alwaer & Clements-Croome, 2010). (Berardi, 2013) provides a comprehensive definition of “sustainable building” which covers sustainability in all its major domains: A sustainable building is “a healthy facility designed and built in a cradle-to-grave resource-efficient manner, using ecological principles, social equity, and life-cycle quality value, which promotes a sense of sustainable community.”

The comparison between these two terms demonstrates that “green” consider buildings as a mere consumer of energy resources which have a negative influence on the environment; therefore, it aims at minimizing its impact by replacing renewable energies and reducing consumption in buildings. However, the term “sustainable” defines buildings in a broader context. It aims at social aspects, cultural issues, traditions, human health, safe and healthy environments, etc. This means that it considers building in a dynamic interaction between different aspects of the human life while the impact of building on physical and psychological well-being of its residents is under measurement; therefore it shifts the aim of the building from a physical place which merely consumes resources to an environmentally friendly facility which provides health and comfort.

In this study, the term “sustainable” better identifies the objective of the research. Since, residents’ acceptance and satisfaction, as well as their sense of well-being and comfort, are at the focal point of designing the building and its features.

In this study, the term sustainable refers to buildings that have been built “green” due to their compatibility with the environment, while substantial factors of human health and well-being have been added to this value.

3-1.3 The definition of Sustainability Living Lab (SLL)

According to (Andersson & Rahe, 2017) “a sustainability living lab aims at challenging norms and providing a platform for new and extended collaboration where actors and users can jointly explore new ways of sustainable living” and the goal is “to develop innovations that, apart from improving environmental sustainability and being economically viable, may also have positive effects on wellbeing." According to this definition, one important responsibility of SLL is not only to test innovative solutions for reducing environmental issues but also to provide a protected, comfortable, and healthy environment for its potential residents. Since human beings spend most of their life-time inside the buildings, the importance of providing living spaces where do not put residence life at stake is a necessity. Another important aspect of a sustainability living lab is emphasized by (Liedtke, Geibler, et al., 2012) known as a user-centric approach. It described SLL as a socio-technical infrastructure for creating, implementing, and testing sustainable innovations with and by potential users. Here, like general definitions of living lab, users also play a fundamental role in the innovation process. Since they are the ones who use technology, their satisfaction and acceptance of products and services is a determinant factor for the success of building-related technologies in achieving environmental goals. (Schuurman et al., 2012) defines SLL a user-centric process in the context of living and working practices. According to (Romero Herrera, 2017) three aspects of user-centric approach in SLL are provided as follows: 1) Being a realistic setting: this includes a real empirical context. 2) Being known as a socio-technical infrastructure: this includes human-technology interactions and behaviors happening in everyday life. 3) Being a test facility: this emphasizes longitudinal research practices in technical and social aspects. These aspects of user-centric approach in SLLs, open up the requirement of broad knowledge in many scientific aspects of the living lab research including social, architectural, engineering, and behavioral science.

3-1.4 Definition of the Sustainable Building Living Lab (SBLL)

In terms of sustainability practices, the role of buildings on environmental sustainability by reducing energy consumption and developing renewable energy strategies cannot be neglected. Buildings can act as a test-bed for designing and operating energy-efficient products and services. If building industry organizations are to succeed in tackling future environmental issues by fostering this energy transition, the best opportunity is to find innovative solutions to strengthen their collaboration in a real -life building context.

The aim of this part is to provide a definition of building living lab with environmental sustainability concept in order to narrow down the scope of the research and clarify the meaning of a sustainable building living lab (SBLL). We have used one of the most comprehensive definitions of sustainability living lab provided by (Von Geibler et al., 2014) as a base structure. According to the definition a sustainability living lab is defined as:

"A research approach aimed at open socio-technical innovation processes, in which users as well as relevant actors of the value chain and the utilization environment participate in the development and application of new products, services, and system solutions. The interactive innovation process takes place in the real environment of the users and/or in laboratories that are configured for user interactions. The innovation process is guided by sustainability criteria and aims to contribute to production and consumption patterns that can be applied on the global and long-term scale and are inter-generationally viable".

Therefore, the phrase "sustainable building living lab" in our research refers to "a particular building facility utilized as a real-life environment which is flexible for testing, developing and refining new products, services, and technologies toward environmental sustainability goals. The aim is to involve users with other actors and stakeholders in the co-creation process, to study the performance of the technology with the particular focus on the users' satisfaction and their interaction with the technological environment." By this definition, the scope of the research will be limited to facilities constructed to act as a living lab. Therefore, in-situ BLLs which are usually set up in the users' private place are excluded from this category. This chapter will continue by probing among cases found in literature which label themselves as BLLs with the aim to be environmentally sustainable.

3-2 The employment of the sustainable building living lab concept

From 28 cases found for furthur research with environmental sustainability objectives, 2 cases are removed because of it particular characteristic; 1) NEST is a BLL consists of a central backbone and open platforms on which individual research and innovation modules are installed for a limited period of time according to a plug-and-play principle. This allows these so-called "units" to be dismantled once the research and development work has been completed, thus making room for new modules (*This is NEST*). 2) KTH building living lab is a comprehensive infrastructure with high flexibility to provide different test environments (*KTH live-In lab*). 2 other cases including Urban Sciences Building (USB) at Newcastle University and Drexel Smart House also removed due to the lack of information regarding the

BLL. Table 3-1 provides all the main characteristics of SBLL cases which are the topic of study in the coming sections.

Living lab Name	Year of construction	Country	Scale & context	Area (m2)	Physical situation
Legacy Living Lab (L3)	2020	Australia	Research facility	251	New
Ripple House	2007	U.S.	Single family detached house	60.4	New
Refract House	2009	U.S.	Single family detached house	65	New
Solar XXI Building Living lab	2006	Portugal	Office building	1500	New
The Fraunhofer-inHaus 1 (Smart Home lab)	2001	Germany	Single family detached house	250	New
Bellevue Building living lab	2001	Swedzerland	School	....	Renovation
Efficiency-House-Plus with Electric Mobility	2012	Germany	Single family detached house	130	New
OU44	2015	Denmark	University facility	8500	....
GreEn-ER Living Lab	2015	France	University facility	4500	....
The Eco_Wall project	2014	Israeli	University facility	2570	New
ASHRAE's Living Lab	2008	U.S.	Office building	3225	Renovation
The Living Lab smart Home (FZI)	2011	Germany	Institutional facility	....	....
The LOW3 prototype solar house of UPC	2012	Spain	Single family detached house	42	New
Concept House prototype 1 by Delft University	2012	Netherlands	Single family detached house	....	New
HSB Living Lab	2016	Sweden	Student housing-apartment	420	New
Coventry University as a living lab	.....	U.K.	University facility	....	New
ZEB LIVING LAB	2015	Norway	Single family detached house	100	New
eLUX living lab at the University of Brescia	2017	Italy	University facility	......	Renovation
Passivehaus Sicily Botticelli project	2013	Italy	Single family detached house	170	New
Toyota Dream House (PAPI)	2005	Japan	Single family detached house	689	New
Joyce Centre for Partnership and Innovation (JCPI) building	2018	Canada	Institutional facility	8981	New
"Benevento" Nearly Zero Energy Building BNZEB	2017	Italy	Single family detached house	70	New
ZEB lab	2021	Norway	Office building	2000	New
CNR-ITC ZEB Laboratory	2019	Italy	Research facility	56	Renovation

Table 3- 1-Name, scale, context, location, and physical situation of SBLLs

3-3.1 Geographical distribution

Environmental sustainability living labs are distributed among 16 countries from 4 continents. 18 living labs are situated in Europe which accounts for 72% of all SBLLs, among which 7 cases are only from two countries of Italy and Germany. Only 4 cases (16%) are located in North America of which 3 of them are identified in the U.S. and 1 in Canada. One interesting finding is that 2 of these cases in the U.S. are built by students for Solar Decathlon competition which can be a sign of the importance of environmental sustainability practices in education sector in this country. 2 available cases in Asia are from 2 countries of Japan and Israeli. While Japan has a long history in environmentally awareness behavior and sustainability practices in buildings, Israeli suffers the lack of case studies regarding green buildings, particularly at larger scale (Cory, 2010). Finally, only 1 BLL is located in Australia which is a research facility built as a Ph.D. research infrastructure focusing on material circularity (Breadsell & Minunno, 2021). Figure 3-1 shows geographical distribution of SBLLs among different continents.

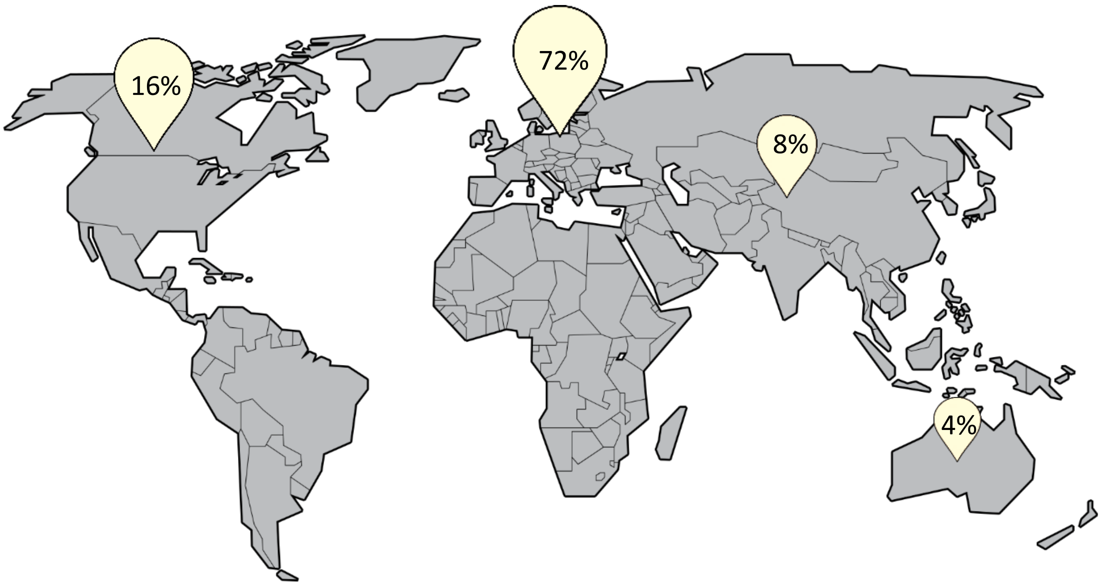

Figure 3- 1- Geographical distribution of SBLLs among different continents

3-3.2 Scale and context

According to different contexts the provided in previous chapter for BLLs, 3 contexts can be identified among SBLLs including single-family houses, public buildings, and research facilities. Of 24 cases of SBLLs that this research has focused on, 10 cases are single-family detached houses, and 1 is student housing in the form of multi-residential apartment. 2

buildings are considered as research facilities particularly for energy monitoring and human-technology interaction while they are flexible in interior layout to act as an infrastructure for different living lab projects. The other 9 buildings are in the public building category; with 4 cases working as office buildings, and the rest are educational buildings in university facilities. Given the fact that residential buildings, particularly single-family detached houses account for a large number of SBLL cases so far, can be a sign of the importance of energy considerations in housing stock and the effort of making people aware of the latest energy-related technologies.

According to the scale of the buildings, 11 cases are less than 500 m^2 which accounts for 46% of all SBLLs. Even, 6 cases of this group have an area of 100 m^2 or lower. This indicates the dominance of small-scale facilities for environmental sustainability practices in LLs. If we consider 500 to 2000 m^2 area as medium scale BLL, only 3 cases (12%) are included in this domain. In total 5 buildings (21%) are among large-scale BLLs with more than 2000 m2 area. Some of them are university facilities and are associated with the campus for testing and implementing infrastructures which can be considered as the urban scale LL while others are single buildings which act independently (The Eco-Wall project, ASHRAE's Living Lab). Meanwhile, the exact sq meter area of 5 cases has remained unknown. Figure 3-2 illustrates the destribution of different scales among SBLLs.

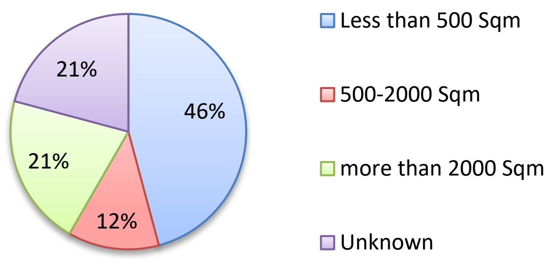

Figure 3- 2- Distribution of different BLLs scales

In addition, the condition of the buildings is either new construction or refurbished. While all single-family detached houses are newly built, only 4 projects are renovated or related to public buildings or research facilities. Generally, the aim of the renovated projects is to improve some aspects of the building to enhance energy efficiency or reduce energy loss. For example, CNR-ITC ZEB Laboratory is refurbished to increase thermal efficiency by minimizing thermal bridges and increasing indoor environmental quality (Danza et al., 2019). The aim of retrofitting eLUX living lab is to use ICT and BEMS in order to have better control over energy consumption (Flammini et al., 2018). The aim of renovation of the Ashrae's headquarter building is to renew a number of building systems to address performance issues (Jarnagin, 2008). The aim was to optimize control systems to increase energy efficiency without compromising the overall comfort (Mastelic et al., 2017). Figure 3-3 illustrates the condition of the buildings.

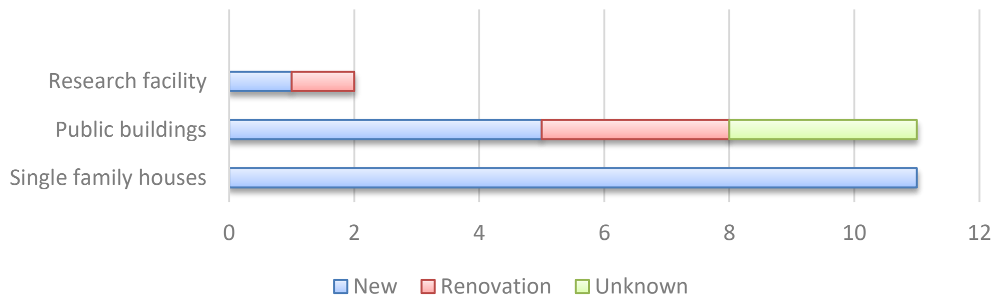

Figure 3- 3- Different conditions of BLLs

3-3.3 Nature of collaboration

One of the major limitations regarding the research on BLLs is the lack of data on many aspects of their partnership. During the research on the nature of collaboration and partnership in BLLs, it was difficult to find relevant data since the number of LLs that provide detailed information in this regard was rare. Therefore it was not possible to have a comprehensive list of BLLs with their partners and their way of collaboration. In this section, I just provide an overview of different partnerships and the name of living labs with their nature of collaboration.

According to the definition of living lab, it is a context for collaboration between different parties including industries, R&D environments such as universities or institutes, public agencies, and users which describes as Public-Private-People-Partnership (4Ps) (Westerlund & Leminen, 2011). This definition is called quadruple helix. This is actually an extension of triple helix model with a fourth partner. Triple Helix model has 3 main indicators. If we consider academia, industry, and government as the main actors of living labs described in this model, there is always confusion about what the fourth helix would be (Hasche et al., 2020). Therefore, in quadruple helix model the fourth partner might be varied. The last model is the simplest partnership model based on academia and industry.

Based on available data, 4 living labs (17%) described themselves as quadruple helix model including Concept house village: Delft prototype, Bellevue building living lab, BNZEB, and CNR-ITC ZEB lab. Triple helix model of collaboration can be found in 5 living labs (21%). LOW3 prototype, Eco-Wall project, GreEn-ER living lab, and ZEB lab are falling into this category. Meanwhile, HSB living lab introduces its collaboration with industry, academia, and society. Legacy Living Lab (L3), OU44 buildings, and ZEB living lab identify their nature of partnership as a collaboration between industry, and R&D environment, which account for 12% of all projects. It is worth noting that this information is based on the living labs' claim, and not on the author's personal perception. Figure 3-4 illustrates these findings in a pie chart.

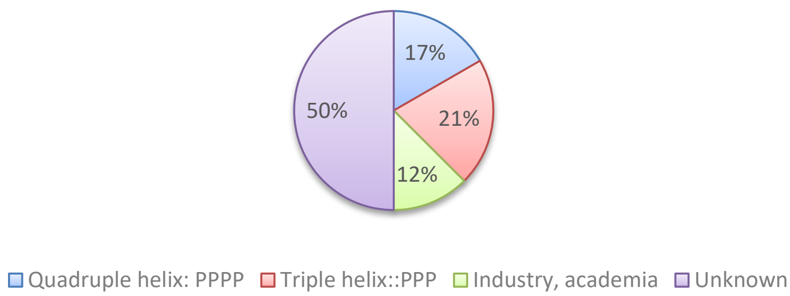

Figure 3- 4- Distribution of collaborative methods among SBLLs

3-3.4 Location and the main source of initiation

According to the list of living labs, their location, and main sources of initiation which are available in Appendix 2, there is a direct relationship between the sources of initiation of BLLs and where they are built. Of 8 BLLs which are initiated by universities, all located at university campuses, constitute the majority and account for 36%. This number includes both single-family detached houses and public buildings such as university facilities and it shows the scientific importance of SBLL which is either constructed as a university facility on a large scale or as a small scale test-bed such as infrastructure or single family detached houses. Besides, 4 projects conducted by scientific institutions or organizations, constructed in the organizations' campuses. Domain of activities for these institutions or organizations is either national or private. Apart from this, 3 BLLs (14%) are initiated by a joint program or collaboration between parties in which university, and/or scientific organization is its main actor. These living labs are also built on university campuses. As a result, 15 living labs

(68%) are initiated by R&D environments; this is while the main source of initiation in 5 projects (23%) has not been clarified. From this, 4 projects are also built on university campuses, and 2 are located in an urban context. Only in 2 projects, government and industry have been the main driving force; efficiency house plus is built at the federal ministry of transport, building and urban development, and Toyota dream house PAPI at Toyota home. Figure 3-5 describes the distribution of various sectors which initiate the SBLL projects.

As mentioned in previous section, university has been one of the main indicators of partnership and collaboration; therefore, it was not a surprise to see larger numbers of BLLs are initiated by R&D environments. This clarifies the scientific part of the living lab and illustrated the role of academia in this regard.

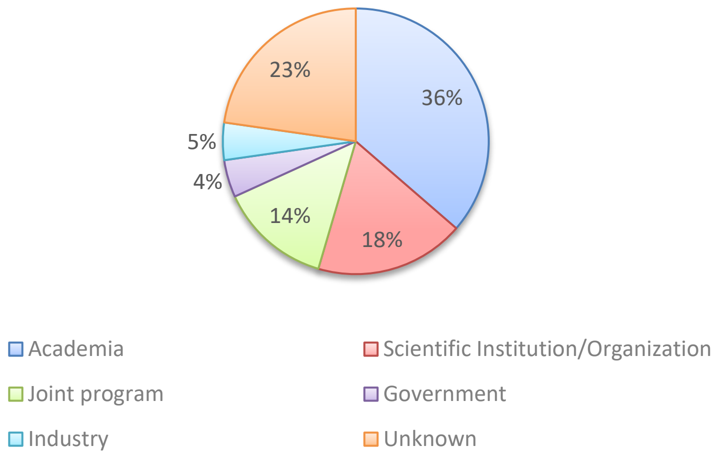

Figure 3- 5- Distribution of sectors as the main source of initiation of SBLLs

3-3.5 Domains of activity

In this section, we will provide an overview of the technologies implemented in SBLLs to test environmentally friendly strategies in a building context. The classification for the sustainable environment strategies are including 1) Energy-efficient strategies, 2) Energy systems, 3) Methods for indoor environmental quality and 4) Material circularity. Other environmentally friendly strategies such as water conservation, food generation, and e-mobility are also included, but in different categories.

A variety of technologies are used to reduce the waste of electricity and heat in BLLs illustrated in Figure 3-6. Among intelligent technologies, BEMS is implemented in most projects. Heat recovery system is widely used in buildings with ventilation systems for thermal recovery. Occupancy sensor is used in more than half of the cases. The usage of this method is either as a motion detector for lighting or to control heating, ventilation, and air conditioning system. Among energy-efficient lighting strategies, LEDs with dimmer technology are highly in practice, while OLED lighting is only implemented in one case. 2 methods of free cooling and active chilled beam used for ventilation and cooling respectively have received less attention in BLLs with only one case for each method. In general, there is a broad use of smart technologies such as BEMS, occupancy sensors, smart plugs, smart lighting, etc. which indicates the importance of digitalization in building energy management. Also, worth to note that there has been less effort on cooling systems, while major attention has been given to heat conservation strategies.

Figure 3- 6- Distribution of Energy Efficient strategies among SBLLs

Energy systems in BLLs are varied from producing renewable energies onsite, to using different types of storage systems to save energy (electricity and thermal). Producing heat and electricity by means of fossil fuel (gas) also falls in this category. As predicted solar energy is the most popular type of renewable energy production used onsite. The fact that PV panels were even more popular than heat pumps might be the simplicity of their installation in every part of the building; however, the circularity of their materials can cause problems. Given that PV panels are the most prominent method of generating electricity and are available in all cases, in some cases they are specifically dedicated to heat generation. Solar collector for hot water is also used for nearly half of the BLLs. Contrary to solar; wind generating electricity has received the least attention among cases due to the limitation of space and also the availability of good wind, in an urban context. Only one case (Eco-Wall project) uses a wind turbine to generate energy at a small scale; yet the main reason for its installation is to educate students.

A large number of cases used energy storage systems in different ways such as batteries integrated with PV, or tanks to store hot water. Meanwhile, some cases use PCM as a kind of passive strategy to store heat. Finally, a low number of CHP units which uses fossil fuels (mostly gas) indicates that energy production through the use of fossil fuels is not popular in the building industry. Figure 3-7 provides an overview of the distribution of energy systems among BLLs.

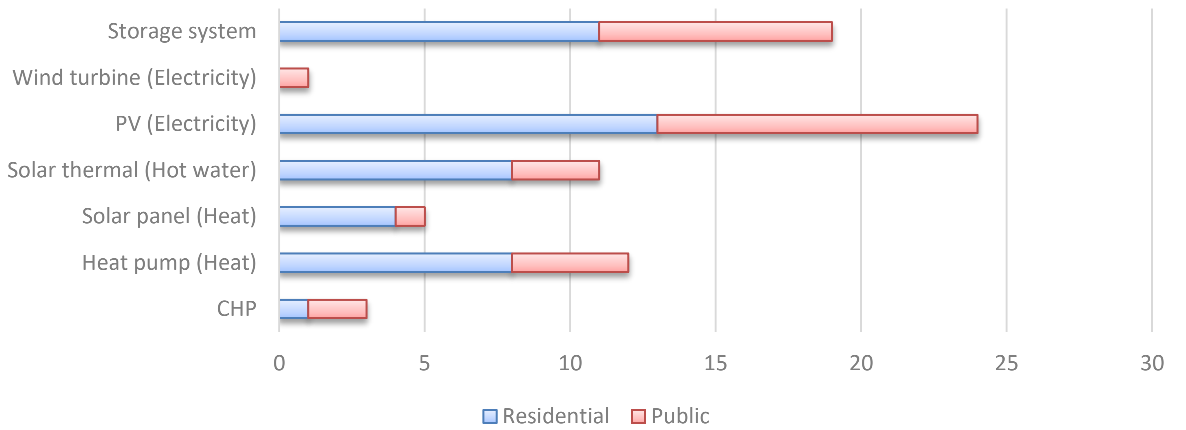

Figure 3- 7- Distribution of Energy Systems among SBLLs

Consideration regarding using materials in buildings has different aspects. Interesting to note that only one case was primarily aimed at material circularity (Legacy living lab) while for other cases it is assumed among one of the scenarios to reduce energy and carbon footprint. BLLs have various approaches for this aim; some of them use the cradle to cradle scenario by pre-fabrication, designing for disassembly, and applying recyclable and re-usable materials. It is found that pre-fabrication and re-usable materials, as well as design for disassembly, are only used in residential buildings. Overall, materials with bio-based nature have been used in more buildings. 7 BLLs in this category consist of timber structures and wooden elements. It seems bio-based material has been more implemented in small-scale structures such as single-family detached houses, although there are examples of public buildings such as ZEB laboratory in Trondheim. Finally, only one case was interested to use local materials to reduce CO_2 emissions from transport. Figure 3-8 indicates an overview of the distribution of material circularity in BLL cases.

In general, material circularity approach has received more attention in small scale structures and single-family houses, while there is a serious need for public buildings on a larger scale to test this approach; particularly when it comes to dis-assembly and pre-fabrication, which are among the best possible strategies to reduce energy and waste from materials.

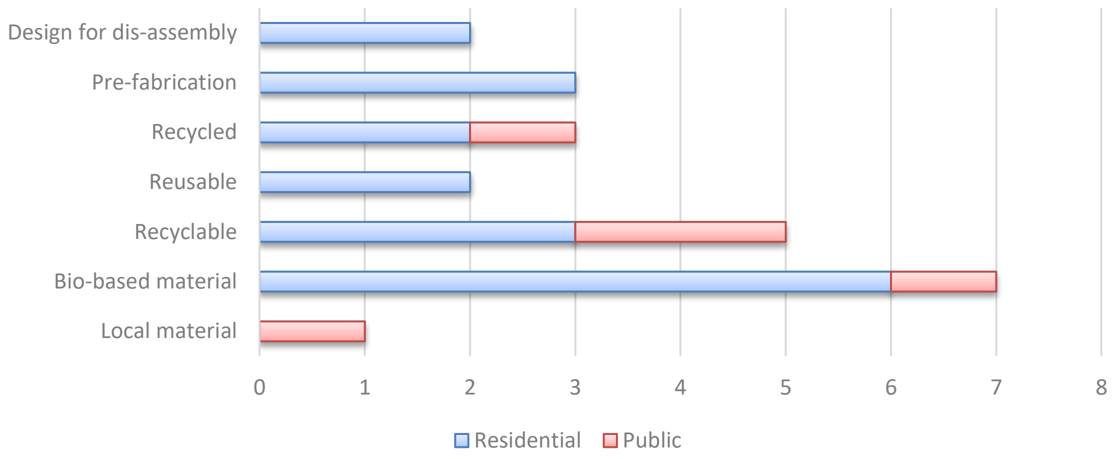

Figure 3- 8- Distribution of Material Circularity among SBLLs

Technologies related to indoor environmental quality are considered in 4 categories of thermal comfort, sound comfort, visual comfort, and air quality. And the technologies used for each category consist of systems and sensors. Systems are technologies which used to provide convenience, while sensors or meters measure the level of this comfort. Figure 3-9 describes the distribution of systems and sensors in different aspects of IEQ in BLLs.

Thermal comfort has been the major indoor environmental quality practice in SBLLs. This includes temperature and humidity sensors[3]as well as systems such as water radiators, under-floor heating, air conditioning, and radiant heating and cooling. 21 cases implemented temperature sensors and 15 cases uses humidity sensors in their indoor environment.

Air quality which has been the second major aspect in IEQ among SBLLs includes HVAC systems, sensors for CO2, particle concentration sensors, and air change rate measurement. Regarding visual comfort, while 10 projects provide controllable blinds, some of them are automated which are integrated into illuminance sensors and others are manually controllable. Overall, sound comfort has received the least attention; only 6 cases are equipped with sound

[3] These two parameters are also related to air quality aspect, but here it is decided to be in one category under thermal comfort.

insulation materials and 3 cases with sound meter. This is while most of the educational or residential buildings are located in populated sites such as university campuses which require more attention for sound disturbance.

Figure 3- 9- Distribution of technologies related to Indoor Environmental quality among SBLLs

By comparing the four main environmental sustainability strategies applied in buildings, it becomes clear that strategies for energy generation onsite and enhancing indoor environmental quality have been the most widely used methods, while material circularity has received less attention so far. This might be related to the nature of BLL activities which are used as a test-bed to study human-technology interactions, and material-related practices do not have any relationship to human interaction. Also, it can be used only once by constructing and deconstructing the building. That is why projects such as NEST emerged as an infrastructure to facilitate these types of activities. Figure 3-10 provides an overview of the popularity of environmentally friendly strategies among SBLL cases.

Other environmentally friendly strategies including food generation, water conservation, and electric mobility have also been the topic of interest in some SBLLs. Strategies for managing water have been widely used so that half of the cases proved that they have water management systems in different forms, ranging from water measurement for water consumption to different solutions for reusing rainwater. Among these projects, one (GreEn-ER Living Lab) has the most effective method of water conservation by which 40% of the water consumed in the building is provided by rainwater. Only one attempt has been made toward food generation which the aim was to provide sustainable housing for the future (HSB living lab).

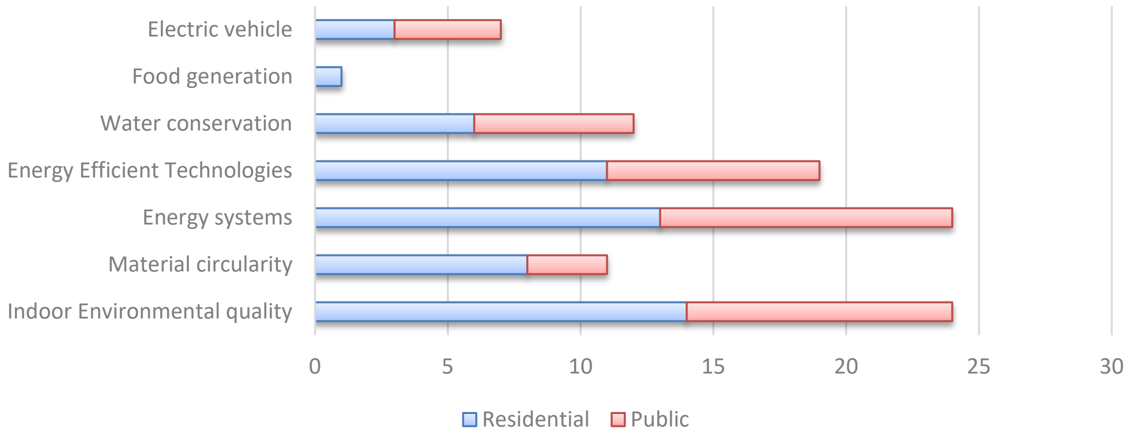

Figure 3- 10- Distribution of environmentally friendly strategies among SBLLs

3-3.6 Secondary goals for environmental sustainability building living labs:

This section will introduce BLLs with dual objectives; BLLs which aim to be environmentally friendly, while at the same time they have been used as a test-bed for a second concept which can be AAL or Educational purposes.

1) Ambient Assisted Living (AAL):

Apart from environmental sustainability as their main concept, several BLLs have expanded their activities in examining and developing assistive technologies and solutions to support independent living for seniors as well as ubiquitous technologies for comfortable living in smart houses of the future. The names of the BLLs with their descriptions regarding AAL as their secondary goal are provided in Table 3-2. As it is predicted, all 3 cases are single-family houses. While 2 other projects mostly focus on healthcare and technologies to support independent living, Toyota Dream House (PAPI) uses home assistive services for automation and functionality to facilitate life. Interesting to note that “The Fraunhofer-inHaus 1” which is the first case of BLLs emerged in 2001, in Germany, has included both concepts. This shows that Germany is one of the pioneers in both BLL concepts of environmental sustainability and AAL.

BLL name	**Description of the AAL as the secondary goal**	**Source**
Toyota Dream House (PAPI)	New technologies utilized for home assistance services and automation of functionalities	(GhaffarianHoseini et al., 2013)
The Living Lab smart Home (FZI)	It provides innovative solutions for healthy living and efficient, digital healthcare	(*FZI Living Lab smartHome/AAL*)
The Fraunhofer-inHaus 1 (Smart Home lab)	It has been used to research on intelligent living in the future by testing new materials, innovative building technology, and electronic assistance systems for smart homes and senior-friendly construction.	(*Fraunhofer inHaus – research for the future of living*)

Table 3- 2- Name and description of SBLLs with AAL as their second goal

2) Education:

BLLs included in this analysis pertain that they focus on environmental sustainability as their primary goal. However, they introduce training and educational practices as a mutual practical goal in the building. The methods they have used to apply this goal are varied between cases. We categorize 2 different approaches in this regard:

a) Some BLLs defined educational practices as on-going activities taking place in the LL and they managed to do that by enhancing students’ learning experiences through experimental learning opportunities. These kind of activities affects the design of the Building; For example, mechanical and electrical installations, as well as energy generating systems, must provide easy and safe access for students and the faculty. They should also provide students with wide access to data regarding building performance under real-life scenarios (Bhavsar et al., 2020). Some of them have such a flexible design so that the building performance can be developed by continuous testing and doing improvement by rebuilding parts of the building (Time et al., 2019). This group of BLLs is classified in the category of public buildings, either being a university facility or an office building where accomodates scientific or educational staff. Since educational practices in building systems are associated to engineering students regarding sustainability practices, one can still categorize them among environmental sustainability activities.

b) Other BLLs have different approaches to teaching and training students. They highlight the importance of their LL as an innovation infrastructure in higher education by involving students and academics in design and construction process of the building. In other words, they use BLL setting as a social ecosystem or an innovation arena to foster experience-based learning, co-creation, and collaborative learning processes between students, faculty, and stakeholders (Masseck, 2017). BLLs participated in U.S. Solar Decathlon[4] competitions can be included in this category. Among 3 cases that participated in this competition including Ripple House 2007, The Refract House 2009, and LOW3 prototype 2010; only one of them (LOW3 prototype) admitted educational purpose among predefined goals of the BLL. However, based on the nature of Solar Decathlon competition, its purpose is to provide a unique training that prepares students for being valuable workforces in the future and to educate students and the public about the latest material and technologies in smart high-performance houses (Solar Decathlon); Therefore, all three cases are included in this category. The name and description of cases with educational concept as their second goal is provided in Table 3-2.

[4] The U.S. Department of Energy Solar Decathlon is a collegiate competition that prepares the next generation of building professionals to design and build high-performance, low carbon buildings powered by renewables. The first competition was held in 2002 and takes place every two year while challenges more than thousands of students each time.

BLL name	Description of the educational purpose as the secondary goal	Source
ZEB lab Trondheim	The laboratry used by people as an ordinary office building or for educational purposes which becomes a sourse of continues experimental data.	(Time et al., 2019)
Joyce Centre for Partnership and Innovation (JCPI) building	The building is designed as a living lab where students, faculty, reserchers and industry are able to monitor and validate the performance of this state-of-the-art facility.	(Bhavsar et al., 2020)
eLUX lab	The building serves as a living lab to monitor the daily conditions in educational spaces.	(Flammini et al., 2018)
The Eco-Wall project	The building is a location for learning sustainability but also a place for demonstrating it to the entire public.	(Cory, 2010)
GreEn-ER Living Lab	The building is hosting master level training, for students of “Energy, Water and Environmental Engineering School”	(Delinchant et al., 2016)
LOW3 prototype solar house	The Living Lab forms part of a new, emerging educational ecosystem, which links formal teaching with informal learning.	(Masseck, 2017)
Refract House	No description	(*Solar Decathon 2009*)
Ripple House	No description	(Wong et al., 2010)

Table 3- 3- Name and description of SBLLs with Educational concept as their second goal

3-3.7 The level of BLL ambition towards environmental sustainability goals:

SBLLs have various ambitions toward environmental sustainability. A glance at Figure 3-11 shows that half of the projects indicate that their goal was being a ZEB or nZEB. One of these BLLs is part of a larger research project of ‘I-ZEB towards intelligent zero energy buildings for a smart city growth’. Only 1 project could reach energy plus and 1 project could be positive in energy use. Both of them are single-family detached houses and both were constructed as part of larger-scale projects. The former is part of the network of energy house plus in Germany and the latter is part of the suslab North West Europe network (suslab NWE). Despite 2 projects which have been certified as LEED, the remainder SBLLs did not mention any particular ambition in terms of their environmental sustainability practices.

In general, it can be concluded that being a Zero Emission Building is a popular ambition for all types of buildings including single-family houses, public buildings, and BLLs which function as infrastructure, while the goal of being positive in energy only used in single-family houses, also, only public buildings have been certified as LEED.

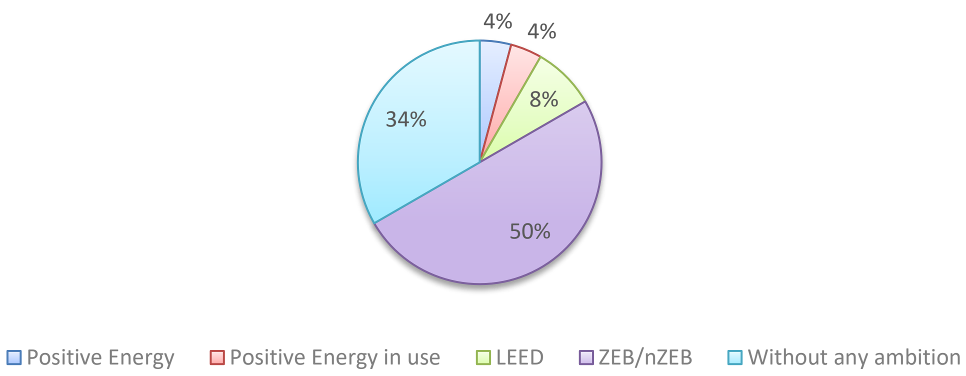

Figure 3- 11- Distribution of environmental sustainability ambitions among SBLLs

Although the majority of BLLs (66%) expressed their level of ambition toward environmental sustainability, their approach to overcome the barriers to reach their goal is different. For example, some of them aim to be ZEB by design for disassembly, deconstruction, and resilience (Legacy Living Lab (L3)). Some others looking for innovative solutions of using solar energy systems to achieve this goal; Solar XXI building living lab, Ripple house, Refract house. Table 3-3 provides an overview of BLLs with their level of ambition to be environmentally sustainable.

The level of environmental sustainability ambition	BLL name	Environmental sustainability approach
Positive Energy	Energy House Plus with electric mobility	Latest housing construction technologies/ energy saving and generating systems
Positive Energy in use	The concept house village: CH prototype 1 by TU Delft	Energy reduction, energy recovery, energy generation
ZEB/nZEB	Legacy living lab (L3)	Decarbonizarion by design for disassembly, deconstruction, and resilience (3DR)/ new products and different contrustion methodologies/ the use of intermediate spaces in domestic architecture
	Ripple house	Designed to harvest all energy from sun
	Refract house	
	Solar XXI building living lab (NZEB)	Integration of solar energy systems in buildings/ focusing on solar energy and passive systems for heating and cooling
	LOW3 prototype solar house	Low energy, Low impact, Low cost
	CNR-ITC ZEB Laboratry	Minimization of thermal losses with the reduction of the existing thermal bridges and the thermal transmittance/ conservation of thermal mass/ Increase the IEQ
	"Benevento" Nearly Zero Energy Building BNZEB	"thermodynamic lab" Reducing energy demand by improving indoor liveability in terms of comfort
	Passivehaus sicily	Reducing energy demand by using passive strategies for heating and cooling / certified as a passive house
	ZEB living lab Trondheim	The integration of new energy saving and producing technologies
	ZEB lab Trondheim	Material and technological structure/ energy generating system/ reduction in energy demand
	Joyce Center for partnership and innovation (JCPI)	Construction materials and technologies/ renewable energy technologies
	GreEn-ER Living Lab	Using heat of the server room to heat the lobby
LEED	The Eco-Wall project	No particular approach mentioned
	ASHRAE's Living Lab	No particular approach mentioned

Table 3- 4-BLLs with their ambition and particular approach toward environmentally sustainability

Furthur considerations:

One important finding is related to the large number of single-family detached houses among BLLs. However, this might raise a question of why all these technical and socio-technical practices are taking place in single-family houses, while the majority of people in cities live in apartment blocks. The reason might be the limitation of time to construct the building as well as economical considerations. Since many of these cases are built based on scientific research from universities, the allocation of land and budget for constructing such research facilities are limited. Another reason might be the temporary nature of these buildings for living and research. Some cases are even built for limited years (concept house villiage:delft prototype), they are built to be deconstructed and designed for disassembly (Ripple house, Refract house) which is logical to have small scale structures for the BLL. The last reason is that they aim at examining the impact of technology in routine life and the focus is given to the interaction between individual users and technology which is easier to be examined in a single-family home context. However, there have been some trends in recent years, toward co-housing and living in a shared place. According to literature, the importance of shared spaces in residential areas is becoming more evident due to aging, reducing the land footprint, minimizing energy consumption and waste materials, and in order to increase pro-environmental behavior among residents (Marckmann et al., 2012). Single-family LLs are mostly examining the impact of technologies on individual behavior and lifestyle, while they underestimate the influential role of social life in supporting sustainable behaviors among residents. Of all SBLLs with residential function, only one case -HSB living lab- aimed at co-housing by using the living lab as students' dormitory. KTH LiL also has similar projects such as co-living and co-kitchen (*KTH live-In lab*). What makes HSB living lab different and more valuable is that the test platform is provided for students to live for the long term, therefore students do not think they are under experiment; besides, all the social and socio-technical monitoring happening while they are living their routine life which makes the results of the experiment more reliable. Considering this, there is a need for BLLs to research the impact of social life on creating environmentally sustainable behavior by increasing environmental awareness among habitats. In addition, since the aim of BLLs is to examine new building technologies in a real-life context the need for multi-residential apartments to act as a living lab for testing materials and services is strongly required.

Another finding is that there is a limited number of BLLs who have involved users or partners in ideation and design phase. ZEB lab Trondheim (Time et al., 2019), HSB living lab (Elfstrand et al., 2017), and the Delft prototype in concept house village project (Eekhout & van Timmeren, 2016) are among BLLs that used early-stage partnership to develop social and technical aspects of their projects; while there is no evidence of this in literature regarding other BLL cases. User engagement has been one of the main indicators of living lab activities. Depending on scale and context of the LL, users might be from various groups including students, employees, residents and etc. (Leminen & Westerlund, 2012) is precieved users as subjects to be studied in a controlled laboratry environment, or can become equal-co-creators, at various stages in order to contribute to the innovation process. (Compagnucci et al., 2021) also, describes 3 different approaches which identify the role of users in LL process: 1) an approach in which the user involvement is limited to passive user feedback. 2) a co-creation approach in which users and stakeholders work together in an interactive way. 3) an innovation approach in which users innovate themselves. Based on the finding from cases, only the first two approaches have been used in BLLs, therefore the role of users are either passive users or active contributors. While the number of cases with the inclusion of active users is low, most of the BLLs use passive users during the experimentation process. Meaning that they are included in the BLL context for experiencing and learning technologies as well as providing feedback for stakeholders. Apart from active and passive users which are typical in LL practices, there are some other users that the reason of their presence is that they are the natural occupants of the building. BLLs of this type are mostly among public buildings where designed for a particular function prior to act as a LL setting. Since the calculations of energy balance, and measuring IEQ conditions in such buildings are reasonable only with the availability of occupants. The role of these users is limited to occupants and they do not interact with the technologies implemented in the building to provide any feedback. In case of giving feedback, it will be limited to their level of satisfaction from IEQ in the building. If we refer to 3 types of users described by Compagnucci et al (2021) as passive participants, co-creating contributors, and designing innovators (Cui & Wu, 2016), this research will define a new group of users in BLL labeled as "uninvolved users". They are defined as occupants whose availability is necessary for the BLL context; otherwise, the reliability of technologies cannot be verified. They act as experimental parameters giving variations in loads with their use (Time et al., 2019). However, they have minimum or no interaction with technologies in the building, and their involvement in LL activities is confined to their presence or limited feedback. Hence, we can conclude that although many of the building facilities label themselves as living lab, they do not act as a living lab since the main criteria of LL activities -which distinguishes BLL from other socio-technical sciences- is active user-involvement in co-creation process.

And finally, this research draws the readers' attention to the increasing utilization of intelligent technologies such as BEMS, smart meter, smart grid, sensor technology, etc. in SBLLs. Also, it highlights that even from the early stage of BLL evolvement; ICT has played a crucial role in the development of sustainable design. In fact, one of the main reasons for shaping BLLs is testing ICT in a real-life setting. Most of the SBLL cases in this research were equipped with BEMS to control and monitor energy as well as the performance of various services and comfort in the building.

According to the definition by (Clements-Croome, 2011) “An intelligent building is one that is responsive to the requirements of occupants, organizations, and society. It is sustainable in terms of energy and water consumption besides being low polluting in terms of emissions and waste; healthy in terms of well-being for the people who living and working within it; and functional according to the user needs.” Since there are a variety of systems implemented in the building, and many buildings are occupied by a large number of users, the balance between the satisfaction of users and the energy consumption by systems should be at the focal point. Only in this situation, it can be said that the building has an environmentally friendly behavior. Smart systems tend to facilitate this behavior by integrating systems and people in the built environment.

However, being intelligent in the building should not be considered a goal, instead, it should be seen as one solution among all, toward sustainability and comfort. During the literature review among SBLLs, only a limited number of cases were trying to use or test innovative passive environmental strategies in the building. This reflects the growing effort to deploy active strategies and intelligent systems. It seems that companies in the building industry are outpacing one another in terms of technological innovations. However, one should consider that while the ultimate goal in building design is simplicity, rather than complexity (Clements-Croome, 2011), applying these technical solutions should provide power for the occupants and facilitate their living instead of making it complicated and unmanageable. Hence, there should be a limit to the number of smart systems implemented in a building which requires user interaction; or a great deal of attention should be paid to their way of utilization so that they can be used intuitively. Also, in terms of environmentally sustainable behavior, passive strategies should be given greater priority, as they are the most environmentally friendly strategies that can be used in buildings.

This chapter will finish by opening a question for future research: to what extent it is essential for the buildings to be smart in order to be environmentally sustainable? And how much intelligent technologies can assist to reach these environmentally-friendly goals?

3-3. Lessons learned

This chapter tried to provide answers to the second group of research questions:

RQ2: How environmental sustainability concept has been employed in SBLLs?

A) *What are the main indicators to define a SBLL?*

B) *In which scale and context SBLLs have been implemented?*

C) *What trend can be found in SBLLs in terms of their actors and initiators?*

D) *How do SBLLs approach toward Environmental sustainability goals?*

E) *What is the level of ambitions in SBLLs toward environmental sustainability goals and how do they try to reach their goal?*

It started with a brief introduction of environmental sustainability and the aim of sustainability in buildings. It is realized that the term "sustainability" in buildings has generally understood as environmental sustainability because of its practical measurement. And the reason for selecting the term "sustainable" rather than "green" for BLLs is that sustainable buildings consider broader aspects of sustainability such as well-being and human life, which green buildings do not include. Sustainable buildings consider the balance between energy consumption and energy production while they do not sacrifice human convenience and well-being during the building life.

Main indicators of SBLLs can be described as 1) a real building facility, 2) having flexibility in testing, developing and refining technologies, 3) including environmental sustainability as their main concept of activities, 4) involving users as co-creators, 5) following the goal of testing innovative technologies, users' satisfaction, and human-technology interaction.

While SBLLs are distributed among 4 continents and 16 different countries, Europe consists of the majority of cases. 3 contexts can be identified for BLLs including single-family house, public building, and research facility. The scale of the projects is varied from a small-scale facility, to medium scale, and large scale facility. The majority of the buildings are among small-scale facilities and single-family houses which highlights the importance of the housing sector in considerations regarding environmental sustainability. The situation of houses is newly built while other cases are either newly built or renovated.

It is found that there is a direct relationship between the location of the projects and their initiators. This shows that universities are acting as the main driving force for SBLLs. Most of the projects are built at university campuses or scientific institutions. Even for the projects initiated by a collaboration program, universities play a major role. In contrast, companies and government have little role in initiating SBLL projects. This study has found that government-initiated SBLLs are likely to be part of a larger-scale project. The nature of collaboration among SBLLs shows that the majority of projects follow 3P and 4P models. What is clear is that academia and industry are the 2 main actors in all SBLL activities.

There are 4 main domains that SBLL activities take place to follow environmental sustainability goals: 1) Energy efficiency, 2) Energy systems, 3) Indoor environmental quality and 4) Material circularity. Apart from this, their activities can be expanded in other domains such as food, water, and e-mobility. In energy-efficient strategies, most of the projects draw their attention to digitalization and heat conservation. Among energy systems for producing and saving energy, electricity production with solar PV panels is used in all projects while strategies for heat generation and hot water with sun have received less attention. Due to their easy installation and integration with buildings, PVs are even preferable to heat pump systems. As expected, the main focus of SBLLs has been on using clean and renewable resources and fewer attempts have been made on producing energy from fossil fuels. Design for cradle to cradle has been the main aim of the projects which use material circularity as one of their environmentally sustainable strategies. Also, related practices have been used mostly in small-scale buildings. For IEQ, 4 aspects of air quality, thermal, visual, and sound comfort have been considered. The majority of the projects use thermal comfort-related technologies which indicate that it is the main aspect of IEQ considerations in indoor spaces. Evidence of sound and visual comfort technologies is low and there is a need for more attention to these aspects of IEQ. To sum up, it is found that energy systems and IEQ strategies are used in all projects, while material circularity has been less in practice. Among other environmental-friendly practices, water conservation has received more attention. Providing e-mobility requires larger-scale development of city-wide infrastructure, which is probably why many projects have been conservative in entering this field.

It becomes clear that SBLLs differ in the level of ambitions and approaches to environmental sustainability. While there has been a growing trend towards building ZEB / nZEB projects, fewer projects are trying to be certified as LEED or be a positive energy building prototype. Some projects use a combination of 4 main domains of actives, and some others try to focus on one or two strategies.

Finally, to answer the main research question, the study can indicate that in general, BLLs have employed a variety of approaches toward environmental sustainability concept and they differ in the level of ambitions to reach this concept. While they use different methods of partnership in their co-creation process, R & D environment plays a major role both as initiator and the main actor in most of the projects. In addition, this study has found that some SBLLs have a secondary concept for their activities, among which educational concept has been more popular. The study has found a drawback in BLL activities which is the lack of involving users during the co-creation process. Also, apart from 3 groups of users identified in BLL context from previous literature, this study has identified a new group of participants who are defined as "uninvolved users" and they have the least inclusion in BLL experiment.

04. Sustainable building living labs and User involvement methodologies

Chapter 4 tends to answer the third group of research questions by looking at the BLL from a practical point of view. It aims to find the main aspects of BLL practices and reflect on activities which affect the value of users' feedback during the test.

The chapter begins with a short introduction about various stages in a LL process; then it clarifies the stage in which BLL-related activities mostly take place during the whole LL procedure. Also, it talks about the necessity of the study on user involvement methodologies in BLL context. The chapter continues by providing 2 case studies with more empirical information available related to BLL activities. The reason for using case study research is to conduct a more detailed study of BLL phenomenon. Since case studies are the best choice for describing, comparing, evaluating, and understanding different aspects of issues regarding BLL practices. At the end of the chapter there is a section about the questionnaire and issues regarding the survey accompanied by some reflections on received feedbacks. Finally, it will provide a discussion regarding various aspects affecting practices and methodologies in BLLs, in addition to providing some practical guidelines to increase the involvement of participants in co-creation activities while reducing the risk of dissatisfaction and attrition of users during the LL process.

4-1 Living lab context and user-involvement methodologies

According to a definition provided by (Ballon et al., 2005), a living lab is "an experimentation environment in which technology is given shape in real-life contexts and in which users are considered co-producers". A living lab consists of a multi-method approach toward co-creation by engaging users to participate at different stages of LL activities. Various stages in a LL process are identified by (Coorevits et al., 2018), including 1) The exploration phase, 2) The experimentation phase, and 3) The evaluation phase. These 3 stages are illustrated in Figure 4-1.

Figure 4- 1- Stages in a typical living lab process (Coorevits et al., 2018)

Since the maximum value of the LL is during the time when the concept is being transformed into a prototype, most of the LL studies focus on this phase of LL activities by researching methodologies to increase user involvement in the process. Less attention has been paid to the experimentation phase and it is only implemented at the end of the LL process since it is assumed that the complex interaction between user, environment, and prototype takes place when innovation has reached a certain level of maturity (Coorevits et al., 2018).

One of the major aspects of the experimentation phase is that it must be conducted in a real-life setting by providing a context which is close to real testing condition of the prototype and there are several reasons for this. First, studies show that people interact with the same technology differently in different contexts (Intille et al., 2003) therefore it is necessary to provide a setting for testing the technology which is similar to the related environment. Second, the observation of user-technology interaction is more reliable than other ways of communication with the user during the experiment such as questionnaire; since studies proved that there is a gap between people's words and their deeds (Sanders & Stappers, 2012). Finally, users need a period of time to get to know and communicate with the technology (Spohrer & Freund, 2012) only after this time, they show their real attitude toward technologies and the context. As a result, buildings were constructed or renovated to simulate the real-life testing environment for performing experimentation activities in LL.

Since the main goal of the experimentation phase is to test hypotheses for upcoming issues related to technology, user-technology interaction is at the center of LL activities. Participants face with the new technologies to communicate in a real-life context for the first time. After this stage, the decision of whether the technology must turn back for further refinement or it is ready for the market is made. When it comes to involving users which is the main character of experimentation in a BLL, there is a lack of information in the literature regarding methodologies for involving participants; also there is a question of what aspects can affect their level of involvement in LL experiment. In addition, it is not clear which aspects of the technology or the environment might affect their value of participation and feedback from the LL practice. In the following sections, the research will focus more on these aspects of BLL by including other literature discussions to have an overview of practices in user engagement methodologies.

4-2 Case studies

This section will provide 2 case studies with qualitative analysis and reflection regarding the context and methodologies in BLLs. Case studies are 1) Efficiency House Plus with Electric Mobility in Berlin, and 2) Zero Emission Building (ZEB) Living lab in Trondheim.

The selection of the case studies was mostly based on the availability of information in online literature regarding user participation during the experiment in the living lab. The goal of case study research is to investigate the empirical data available from the case LL practices for recruitment, as well as methodologies used for users' interaction, to broaden the knowledge regarding BLL activities at the experimentation stage.

4-2.1 Efficiency House Plus with Electric Mobility, Berlin

Energy House Plus with electric mobility is the first building of the "Network of Efficiency Houses Plus research Program" initiated by the Federal Ministry of Transport, Building and Urban Development (BMVBS) and funded by the Federal Government. Over 37 buildings[5] is part of the national wide Efficiency Houses Plus network which mostly have been completed between 2013 and 2015 and scientifically monitored ever since (*Strategies for Efficiency Houses Plus: Principles and examples of energy-generating buildings*, 2016).

Energy House Plus with electric mobility constructed in Berlin and opened in December 2011. The aim of this prototype was to promote the sustainable development of the building sector in Germany and strengthen the competitiveness of the German building industry in the European market. The two-story glazed house with 136 m^2 living area intends to demonstrate the feasibility of "Smart" housing, using the latest and most efficient materials and renewable energy sources to be a model for energy efficiency and sustainable construction in Germany.

The house should generate more energy than a family of four consumes in the annual balance. This made possible by photovoltaic equipment, energy management systems as well as information and communication technologies.

[5] Based on 2016 Report from Federal Ministry for the Environmental, Nature Conservation, Building and Nuclear Safety of Germany

4-1.1.1 Goals of users' life monitoring

Apart from the engineering interest which is primarily aimed at the performance of the technology and the feasibility of the theoretical energy self-sufficiency house under practical conditions, social science research intends to evaluate the quality of life to record the suitability and manageability of technologies, as well as the their impact on the well-being in everyday life. In fact, the social science research tends to evaluate how a family of four can cope with the technologies in the living lab. The aim of the research was to examine the suitability of everyday use of the house from the users' point of view; finding out to what extent the living lab is positively perceived and accepted as an energy producer and energy saver? How the family deals with the technology and what problems had to be overcome? Furthermore, whether living in an efficiency house would bring about remarkable changes in the behavior of the residents or they already had an interest in energy saving strategies? Is the supporting technology in the living lab is sufficient to save energy, or individual efforts of occupants to save energy are necessary?

In general the social scientific goals can be summarized as:

1) To determining the users' evaluation of the efficiency house, the user-friendliness of the building technology and living satisfaction of the residence.
2) To determining the environmental awareness, environmentally friendly behavior and energy saving behavior.
3) To identify possible behavioral changes.

The results of this evaluation including the technological usability of the living lab as well as the satisfaction of the living situation were considered as essential parameters of the overall assessment of the living lab success (Schulze).

4-1.1.2 Users' selection method

Two families of four people, was selected through the recruitment process. The selection criteria were divided into several steps:

1) Advertisement criteria
2) Social conditions
3) Letter of motivation and attached photo
4) Personal interview

5) Lottery procedure

The applications call for test family with specific criteria (e.g. the number of family members, the necessity of having driver's license, parent's employment, the age of the children, etc.) was posted on the website of the Federal Ministry of Transport, Building and Urban development. The deadline for the application was more than one month. The questionnaire based on social conditions was made available for download on the website of the Berlin Institute for social research. The families needed to send the application documents by email, or post to the institute.

At the first step, based on the requirement criteria, a total of 132 families mostly from Berlin applied. 48 applicants were excluded at the second stage since they did not meet the requirements for particular social conditions need for the test (no IT professionals, the sex of the children and their age, location of the workplace). In the third step, the motivation letter and photo of applicants were assessed. Applicants with interest in saving energy or those who already had experience with energy efficient way of living or those whom motivation were to build or renovate an energy efficient house for themselves in the near future, were in priority and those who financial considerations were their main concern where excluded. After this selection procedure, 10 families remained who were directed to the personal interview at their own house. The interview includes more detailed clarification of motivation including what would be their plan after 15 months living in the Efficiency House Plus? The interview took more than one hour while video recordings were made. 5 equally eligible families remained from whom one family was finally selected through lottery procedure under the supervision of the ministry.

4-1.1.3 Monitoring methods of users' life

Long-term analysis was an essential part of the study to cover different seasons in terms of energy considerations. Monitoring of the users' life carried out using qualitative and quantitative methods, including 5 survey tools:

1) The weekly logbook (63 in total, every week)
2) Quarterly questionnaires on satisfaction and well-being (5 in total, every 3 months)
3) Questionnaire on environmentally friendly behavior and energy saving (3 times)
4) Qualitative interviews (6-7 times)

5) Participating observation (in initial phase)

The weekly logbook contained online questionnaires for gathering data around the reliability and controllability of technical devices, usage problems, and the well-being of the residence to compare users' output with the technical measurement data after the 15 month test phase. The aim was to illustrate to what extent the subjective perception is in line with the objective circumstances. The logbook contains two types of questions; blocked questions and open questions. Blocked questions mostly consisted of indoor environmental quality (e.g. temperature, humidity, ventilation, and lighting), also hot water and the building management system through control options (smart phone and touch screen). The answers were based on 5 points scale ranging from exactly agree, somewhat agree, difficult to say, to somewhat disagree, and completely disagree. Open questions were more about technical issues during the week.

To record changes in perception of the users during the test period, they were asked to fill out quarterly questionnaires. The questions were mostly related to the general satisfaction with the living environment, technologies, participation in the research, and etc.

The family was also asked to fill out another questionnaire, once before moving in, once after 6 months of living, and once after moving out. The aim was to record any changes in environmental awareness behavior of the users such as energy consumption.

Qualitative interviews served to provide in-depth information assessment related to logbooks and the questionnaires that had been filled out to that point. This also includes children's assessment. The interview was conducted every 3 months, including once before moving in and once after moving out.

Some actions or experiencing particular situations such as dealing with touch screen controls cannot be observable with conducting conversations or filling out questionnaires. As a result, in the initial phase, the usability of technologies was evaluated with the presence of the researcher in the action of the participants.

4-1.1.4 Assessment and Users' experiences

From the selection procedure mentioned before, 2 families were selected to live in Efficiency House Plus each for more than one year; Family 1 from March 2012 to June 2013, and family

2 from May 2014 to April 2015. In general, the monitoring results illustrated that both families felt comfortable and the experiences made over the test periods were consistently positive (Schulze, 2013, 2015). While the users' satisfaction of the building and technology was assessed through weekly logbooks, the impact of life in such a smart living environment on users' awareness and their energy consumption was the subject of reflections by interviews.

Both families found the building layout very comfortable. They were also impressed by furnishings and functional interior design. However, their assessment of living comfort did not merely limited to architectural perspective. It also depends on their satisfaction from the indoor environmental quality ranging from brightness, and acoustics, to temperature, humidity and indoor climate.

Using touch panel and smartphone for the management of building services was mostly intuitive. Even the eight and ten year-old children of the first family could easily operate the lights, blinds, etc. Only the setting of scenarios required an introduction. The smartphone was valued by both families especially as a way of being able to monitor the house when they were away.

4-1.1.5 Results from socio-scientific monitoring

Although both families already had environmental awareness even prior moving in, they illustrated energy efficiency behavior, not only during the living period in the house, but also after moving away. The principle of "lights out, windows closed, heating down" which both families internalized during energy crisis of 1980s, did not changed by living in the Energy House Plus. It means that they did not change their behavior into generous use of energy by knowing the fact that the house is self-sufficient in terms of energy production. Even after turning back to their own homes, they illustrated some particular environmentally friendly life-styles. Both families admitted that living in an energy producing house with highly efficient electrical appliances provides a sense of high quality life. The possibility of monitoring and being able to control energy consumption was very motivating and it was implemented as part of their routines.

Overall, it can be concluded that living in Efficiency-House-Plus protects environmental resources and conveys a high standard of living and sense of well-being in users.

4-2.2 Zero Emission Building (ZEB) living lab, Trondheim

Trondheim ZEB living lab is a single family detached house constructed in 2015. It was initiated by the collaboration of SINTEF and NTNU, and it is part of the laboratory infrastructure developed at the research center for environmentally friendly energy; Zero Emission Buildings (ZEB) whose aim was to develop buildings with low energy requirements and a net zero climate footprint. The laboratory is part-financed by the research council of Norway (*ZEB Living Lab*). It is a test facility to carry out experimental investigations at different levels from envelop to building equipment components, from ventilation strategies to action research on lifestyle and technologies, where the ways users interact with building characterized by high indoor comfort conditions and low energy demand is analyzed (Finocchiaro et al., 2014).

4-2.2.1 Goals' of users' life monitoring

Through several test periods, selected users have used the intelligent house as their own home. The focus of the research has been the users and their use of innovative technology developed through ZEB. The users asked to take control of installations and equipment with interactive user interface including the air conditioning and the energy systems (*ZEB Living Lab*).

1) The impact of ZEB on its occupants and how occupants can affect ZEB in various ways
2) The acceptance of ZEB and ZEB technologies among different age groups (Korsnes et al., 2018)
3) To explore occupants' interaction with automated domestic environments (Korsnes et al., 2016).
4) To understand the role of occupants life phase, age and family situation and their expected or unexpected actions on energy use and peak power consumption (Skeie et al., 2019), (Korsnes et al., 2016).

4-2.2.2 users' selection method

Participants recruited by means of a short media campaign which used to invite households from Trondheim Municipality; encouraging people to be the one who has the possibility to live in a zero-emission house. While there were no priority for applicants who have energy saving or environmentally conscious behavior, the overall expectation was that they would be interested in energy consumption in a zero-emission building.

155 people applied for this opportunity. The selection procedure was based on categories of people including students, families, and seniors. These groups were defined before the announcement, not only based on the current and future demographic changes in the population (Korsnes et al., 2018) but also according to the differences in attitudes and preferences (Skeie et al., 2019). For each category, two groups were selected based on the degree of similarities between participants particularly in terms of age and the number of children (for families) in each category. The final residences of the ZEB living lab were 6 user groups in total including 2 student groups, 2 families with small children, and 2 elderly couples.

4-2.2.3 Monitoring methods of users' life

The experiment with 6 occupant groups was conducted from October 2015 to April 2016. Each group was asked to live in the ZEB living lab for 25 days. Monitoring was carried out through qualitative methods including:

1) Interviews (3 times for each group)
2) Informal meetings
3) Participant observation
4) Daily diary recordings
5) A notebook for guests
6) A camera for self-filming
7) A focus group meeting with participants

Interviews were carried out 3 times; before, during and after the occupancy of each group. Interviews during the stay conducted after 16-18 days after moving in, and after-stay interviews conducted around 25 days after moving out.

Informal meetings were carried out at the beginning and at the end of the 25 days living experiment.

Participants were asked to keep an effort on consistency of the daily diaries to get an overview of the routines in the house regarding the time of occupancy and the type of activities. They could also write down their thoughts, reflections, and experiences during their stay in the living lab.

After finishing all the experiments, a focus group meeting with participants was conducted to exchange, compare and discuss their experiences of living in the living lab (Korsnes et al., 2018).

4-2.2.4 Results from socio-scientific monitoring

Although the experiment was carried out under controlled environment which is the main characteristic of the living lab, the users' preferences and attitudes including the time, frequency, duration and type of using electrical appliances can affect energy consumption in the building.

4-3. Findings and reflections

The purpose of this section is to reflect on the living lab approaches applied in case studies for recruitment and methodologies implemented during the practice phase to have a better understanding of user-involvement procedures in building living lab environment.

According to social science methodology, before starting the experiment in LL, the concept of the research should be explained to users. Communicating the concept to the users in LL took place in 2 different steps: 1) Communicating the concept of the LL environment by introducing the aim of the building (e.g. Zero Emission Building), and 2) Introducing the technologies implemented in LL by providing full instruction and guidance session.

Our case LLs have used different ways of communication for both purposes. One of them provides users with an "instruction manual" about the building and its technological appliances including the aim of the experiment and the methods to be used, as well as a short drop-in visit (five minutes to one hour) with informal interviews (Woods & Korsnes, 2019), (Korsnes et al., 2016). In the case of technology, in order to assist occupants to gain insights into how the technology must be used, the usability of the technology (in our case touch panels for technical house control systems) was evaluated through "participating observation" (Korsnes et al., 2018). The characteristic of this method is the personal participation of the researcher in the actions of people using the technology. The benefit of this is the fact that when participants become directly involved in experiencing a situation, different aspects of their thinking and acting are more observable than making conversations or filling out questionnaires about the operation (Ståhlbröst & Holst, 2017).

User interaction with technologies such as the touch panel and smart phone in one case shows that although users found the technologies highly intuitive and comfortable initially, after encountering a practical problem such as setting scenarios for selected blinds or switching lights and motion detectors, they found it confusing or difficult to control. Besides, they indicate that although technologies are for making life easier and more comfortable, some technologies are not necessarily required if there are other easier manual control options. They also add that they will not miss this technology after they go back to their home (Schulze, 2013). The experiment with other technologies such as different types of lighting switches indicates that users preferred manual light switches to both motion sensors which they were unfamiliar with initially and digital programmable switchers which they found difficult to use without instructions. The results have illustrated the fact that when a technology is challenging for people, they would not have the tendency to use it. This is in line with the findings of (Flavin, 2012) who indicates that people prefer to use technologies that are simple and convenient. Observations also show that users did not use the central control panel continuously, particularly after the problem occurred related to control heating in the house; since they believed that the system could not work reliably. These types of users' reaction regarding the technology are called "non-usage attrition" which is defined as when participants lose their interest to continue testing the technology (Eysenbach, 2005) while they still provide feedback. There is another type of attrition called "drop-out attrition" which is described as "the phenomenon of losing participants to follow up" particularly when they have stopped providing feedback (e.g. filling out questionnaire). The term "attrition" in general is described as "the phenomenon of participants stopping usage and/or being lost to follow up" (Eysenbach, 2005).

When searching for the factors affecting each type of attrition, (Georges et al., 2016) found that drop-out attrition is linked to the research setup, whereas non-usage attrition is linked to innovation-related factors. In both of the LLs, there were evidences of non-usage attrition. The attrition data can direct us to the users' adaptation problem with technology in a real-life context. The main reason can be referred to as the usability problems or when users do not see any benefit to continue using the technology (Georges et al., 2016). In this regard, some studies propose that providing incentives for users or introducing some regular reminders about using the technology and encouraging participants to use them (Ståhlbröst & Holst, 2017), will help users to continue the experiment by increasing the possibility of adaptation to the technology.

Meanwhile, there are some arguments regarding that the living lab participants should have the right to decide whether to participate or not during the co-creation process. They should be entitled to include themselves at any stage of the living lab process or exclude themselves whenever they want without providing a reason (Beutel et al., 2017), (Ståhlbröst, 2008). However, this is true particularly because of the voluntary characteristic of LL activities and this can be applied when co-creation process takes place during a short-term experiment or in the design phase. In contrast, for the practical experiment, when a longitudinal study is running in the laboratory setting or particularly when the financial support is limited, this might cause problems for the experiment. Since it is a waste of time and effort if people participate in LL do not wish to finish the duration of the experiment. Hence, engaging actions are recommended, not only to ensure user's consistency in participation during the whole process, but also to encourage participants to take part in the LL experiment at the beginning. However, there is an argument by (Georges et al., 2016) that incentives only help when the users have to deal with the technology by performing some relevant tasks, but when they have to co-create, the users' intrinsic motivations play a major role. Besides, using financial incentives might attract participants at the beginning but their motivation would be subsided after some time in the experiment.

Some living lab experiments tend to put awards to encourage people to participate in their projects. Regarding this, one study (Logghe et al., 2014) indicates that although applicants expect to receive financial or material rewards, this does not play an important role in their incentives, since they have stated that the ideal reward for them is receiving the research results in which they have participated. In other words, they want to see their value and importance in the experiment (Georges et al., 2016). Another study (Beutel et al., 2017) has suggested to provide an appealing setting in the living lab experiment such as an environment which is pleasant and beneficial for users, rather than giving financial incentives. The study indicates that this proposal is not only beneficial for attracting applicants to the recruitment process but also influential in the continuity and stability of their participation in LL.

However, although none of our case living labs, offer awards to encourage people to apply for the experiment or to continue the test, some particular announcements such as living in a zero-emission lab as a specific opportunity experience, are used. This led to include applicants who eagerly looked forward to take part in a “futuristic” experiment in order to play a role in the advancement of science (Korsnes et al., 2018). For the other case, the life in the living lab with the possibility of using free electricity and e-mobility for more than a year can be considered a benefit itself, although, from the first step of recruiting people, the aim was to make sure that applicants with financial incentive do not be included in the recruitment process. Therefore, it can be concluded that giving promises such as informing users about the research results or explaining the users’ valuable role in the experiment or encouraging them to learn new things by testing new technologies, not only includes those participants with similar incentives but also motivate them continuously during the test. But how researchers can understand participants’ incentives before setting up the experiment? Since incentives will appear sometime after starting the LL activity from their actions and feedbacks.

According to (Logghe et al., 2014), the motivations of users who participate in the lab experiment are different. As a result, while recruiting people for the living lab activity, one should be aware of the incentives behind the applicants’ participation. The difference between recruiting criteria in two living labs would certainly affect the results. In Efficiency House Plus where the selection procedure was based on the applicants’ motivation letter, financial matters did not play role. In additions, major attention was given to select participants who introduce themselves as environmentally conscious people. As the experiment shows, the applicants were concerned about energy during the test and even the selected families expressed good feeling when they knew that the energy consumed was from renewable resources. On the contrary, no motivation letter was asked in the ZEB LL; neither, there was an announcement to recruit people with environmental conscious behavior. This led to the inclusion of participants who do not care about energy consumption because it costs nothing to them (Korsnes et al., 2018). Although the aim of the living lab research was not the comparison of energy calculation among different groups, the participants’ incentive would be certainly important in a ZEB LL activity which aim is to reduce energy consumption.

Hence, the user selection procedure is one of the most fundamental steps in both social and technical aspects of living lab research. Using a multi-stage selection process with a combination of qualitative and quantitative methods where participants are excluded after each stage is the best method for recruiting users (Schulze, 2013). When comparing these 2 LL cases, we understand that the duration of the experiment is an important factor which affects the selection of recruitment methods in LL. For efficiency house plus where the longitudinal study (more than one year) was conducted in the LL, a systematic and strict selection process was employed; while in ZEB living lab where the experiment happened for 21 days, no particular procedures for selecting applicants were applied. This shows that the importance of users' incentives is more apparent when the study takes a longer period. This also reduces the risk of attrition and the possibility of leaving the experiment. Therefore, for setting up a longitudinal study in the BLL, a systematic multi-stage selection process is crucial to find users with similar incentives to the LL activities. However, using a designed selection process is suggested even in short time test periods.

The criteria for selecting users is not only about the objective of the experiment but also based on the scope that the implemented technologies which the living lab brings about. Considering the qualifications required for using the technology or the limitations it brings about, should make researchers apply those selection processes which comply with the user requirements for the experiment. Age, gender, number of residents using the living lab at the same time (e.g. number of family members), personal and professional qualifications, etc. are among quantitative criteria which must be defined for users' selection. For example, to examine the level of satisfaction and acceptance for a technology such as electro mobility, participants must have some professional qualifications such as a driver's license. In addition, they must be employed with a job within the city (and not too far from the city district) to use e-cars regularly. Another example is related to the age of the users which is highly important in the level of their technology-acceptance behavior. Elderly people do not accept new technologies easily since they got used to the way they lived. The evidence from ZEB LL shows that although the heating technology acts properly, elderly couples prefer to have a fire stove instead. It is predicted that with the availability of fire stove, they did not have the tendency to use new heating devices. Therefore for those LLs where the aim is to test a particular technology, it is recommended that the age group be defined precisely.

When setting occupancy time, one should be aware of the goals of the experiment. Users need some time to understand technologies and get familiar with the environment. This time is required to form an attitude toward the new system and prototype. Only after this time, users' interaction and communication with the technology would be reliable. In their study, (Spohrer & Freund, 2012) referred to this period of time as the "honeymoon" period. This can be defined as the minimum time required for every experiment in a BLL.

Limited occupancy time can lead to uncertainties of results, and longitudinal time can cause attrition and increase the risk of leaving by users. In ZEB living lab Trondheim the occupancy time was limited to less than a month. The users' direct description or indirect reactions indicate that the stay time within the house can be characterized by a transition period where new routines did not have time to form, therefore a longer period of time was required to form and stabilize new norms and behavior (Korsnes et al., 2016). On the other hand, the time required for performing a living lab methodology with user-technology interaction can be compared to the time required for an ethnographic[6] study (Lloyd & Deasley, 1998) which requires at least six months. Since in the living lab experiments, users are the reporters and they are asked to have narrative descriptions of their perception from the new context, this time period is necessary to become acquainted with the setting and its basic structure (Ståhlbröst & Holst, 2017). In longer experimental studies such as Efficiency House Plus, there is always a risk of user attrition which was mentioned previously. Occupancy time frame required for an experiment is dependent on the complexity of the tasks or technologies in practice. According this, the time frame required for users' to cope themselves with technology varies. It is clear that it takes longer for elderly people to take part in an experiment and cope with new technological situations such as a smart living lab. Besides, they hardly accept new technologies because they have been accustomed to what they had and the related norms have already been formed (Korsnes et al., 2018). Since the aim of the study is to explore how people can deal with the challenges which have been brought about by the new artifact, it is recommended to consider the users' needs to organize the duration of the study. Therefore when comparing the interaction of different age groups with the same technology within the BLL context (similar to what the ZEB LL was aiming at), the time frame required for each group should be varied based on their particular properties.

The degree of acceptance by users is considered as an important indicator of success in living labs (Schulze, 2013). Therefore identifying some of the influential factors such as architectural or engineering choices in the living lab design would be crucial in the acceptability process by users (Korsnes et al., 2016). The fact that none of the SBLL cases include users in the cooperation process from the early design phase is a determinant factor of this acceptance and satisfaction with the living lab environment during the experiment.

[6] Ethnography is a way of collecting "rich and complex" social data that is not theory driven and the data is allowed to "speak for itself". And its methodology is based on a neutral observer investigating a particular system by being part of that system.

The criticism regarding the architectural layout of the house such as the lack of private space or large window surfaces, even using a particular style for furniture which is not in line with the traditional style that people are accustomed to it, will affect users' perception of the BLL environment. (Scott et al., 2009) and (Liedtke, Welfens, et al., 2012) also have the similar findings in their studies. They believe that when introducing technology into people's lives context, one should be aware of user-bound factors such as compatibility with lifestyles, aesthetics, and comfort; otherwise developing technological solutions will have little or no impact on sustainability. However, experiments indicate that some of these initial reactions of dissatisfaction would be subsided after some time when users get used to the new living environment, although the environmental situation have remained the same (Korsnes et al., 2016), (Schulze, 2013). Therefore, understanding users' attitudes and insight by involving them at the early stage of design, not only for designing technological innovations but also the layout of the building and furniture will contribute to users' acceptance and satisfaction by accelerating their adaptability process.

A glance at the objective performance of each BLL illustrates the fact that social sciences do not play too much role during the design phase of the buildings. This can be clearly seen in selecting the physical location of the building, or designing its layout; meaning that while the aim of the design is energy and functionality, socio-scientific monitoring including coping with the technology, suitability of the house, usability of technology, and satisfaction with the living situation are the factors of success of the living lab project, which is all related to humans and living part of the living lab. Being located in a public or populated site such as a university or federal ministry accompanied by large window surfaces in the façade does not bring a sense of privacy, particularly in the experiment where participants were encouraged to "make the living lab their home" (Korsnes et al., 2016). The experiment shows that since people prefer to have their private space at home, they tend to close the curtains during the daytime and use electric lights instead, which is not in line with the objectives of the experiment. This elaborates the fact that people prefer their convenience and personal privacy over environmental considerations. Commuting challenges have been another issue in this regard. Not all living labs provide electro-mobility options for the residents to commute from living lab to work or doing other urban journeys. Having this in mind, the location of the living lab should be selected based on the accessibility to public transport from every direction of the city. Without any doubt, being relieved from the difficulties of commuting to work or the city center to accomplish their daily routines, will affect the sense of comfort of users during the longitudinal period living in the living lab.

One interesting finding for both BLL cases is that none of them were aiming at co-creation during the living lab experiment. This cannot be seen either in their activities or among the LL goals provided in the literature. Therefore, the LL activities are limited to observation of users' interaction with technology and the environment by gathering users' insight through their feedback. And this is while one of the major differences between LL and other social science methodologies is the inclusion of users in co-creation process. Here, we refer to a definition provided by (Haukipuro et al., 2018) which describes LL as "a way of working to develop new solutions together with the users, right from the early stages of development." Hence, the main aim of involving users in LL activities is not merely being a test object, instead, they have to fill in the gap between ideation and accepted product by the public through their co-creation activities.

When implementing technology for testing in a wider context rather than the building living lab, the availability of infrastructure at a larger scale to support the technology is necessary. This reduces psychological concerns about the challenges of using that technology. For example in the case of electric cars, if there are not sufficient charging infrastructures at the city scale, due to the limited capacity of batteries, the user always has to be concerned about the trip distance. This will reduce user engagement and affects the acceptability of the technology.

The study on the interaction between users, technology, and environment also indicates that residents are willing to invent new forms of usage for technologies and environment to fit them into their lifestyle. For example, some users brought their furniture to the house to make the living environment compatible with their needs, or they used the oven to heat up the space when they found that the heating device does not work properly. This "technology appropriation" behavior is also mentioned by (Dourish, 2003) who believes that users' have the tendency to change the usage of the technology in order to be fitted into their living and working life in an adoptation and adaptation process. This behavior, not only illustrates the complexity of interaction between user, technology, and practices, but also shows the users' tendency to seek for easiest solutions for complicated problems. This is one of the main differences between developing ideas around a technology by designers and by users. While designers look at the problem from a complicated and professional point of view, users come up with simple solutions through hands-on experience. Therefore this research suggests providing flexibility in the environmental design and technology usage in the living lab experiment. This can lead users to develop creative ideas in design and practice of the situation as well as strengthen their motivation for further participation in the living lab experiment.

4-3.1. A comparison between BLL and in-situ LL experiments

Considering users in a living lab with all human-technology interaction processes happening in a controlled laboratory setting, raises the question of whether the same results would had been reached if the experiment had been carried out in the participants private context. According to one study, different generations of LL projects can be defined in a building living lab (Andersson & Rahe, 2017). Table 4-1 is illustrated different generations of LLs to test and evaluate new technologies.

Generation zero	1st generation	2nd generation	3rd generation
The need to assess the performance of a single technology	The need to assess the performance of a system	The need to assess the performance of a single technology and a user	The need to optimize the interface between human behavior and system
Normalized tests and standards	Unoccupied demonstrators	Occupied demonstrators	Co-creation environment

Table 4- 1- Different generations of LLs (Andersson & Rahe, 2017).

The 1st and zero generations are when the assessment of the system or technology is taking place without users. The 2nd and 3rd generations are focusing on the usability of the technology while it is tested by users. In the 2nd generation, testing can be carried out in any context therefore the interaction and acceptance of the technology cannot be understood clearly, since it requires longitudinal observation of user interaction with the technology. Also other important factors such as the environment are not considered in the experiment.

The 3rd generation, however, is based on a research platform which aims to optimize the interface between systems and users in a real-life setting (Andersson & Rahe, 2017). It means that experiment must be implemented in a particular environment while the user is interacting with the technology in a daily routine life. Although this generation addresses a real-life context to human-technology observation and experiment, it does not clearly define the real-world context. According to studies which have been conducted in BLLs, there are two different contexts where the co-creation can take place: 1) One, is the users' natural environment during their regular living and working activities. The experiment can be performed in the user's private house or in their working environment by adding the technology to the context. We call this in-situ experiment. 2) The other is a particular building in the form of a laboratory which is designed and equipped to allow systematic observations, measurements, evaluations and refinement of the hypothesis regarding technology or the system.

While the main aim of LL practice is similar in both settings, which is rating the level of user's acceptability, and satisfaction with the technology, the nature of the experiment is different.

First, as demonstrated by (Ståhlbröst & Holst, 2017) in a laboratory setting where the users are under observation, they do not feel to be in a safe and comfortable environment since they know that their interaction is always under measurement, therefore they might not be confident enough to interact with the technology or to provide realistic feedback. It means that it is difficult to study changes in technology-related behavior in a controlled context.

Second, the way users interact with the energy consuming appliances in case living labs is also something to notice. In the living lab setting some participants made the space warmer than they used to in their private house, since they did not have to be concerned about the energy cost. One group of occupants even used the roof window to cool the house when the temperature was higher than needed. These kinds of behavior are also related to the experimental characteristic of the living lab where people do not care about energy price, technology adjustments, or repairs. Therefore we observe behaviors that do not normally occur in real context.

Third, since the process of adaptability and users' acceptance of the lab environment and implemented technologies is relatively a long-term process, there is a limitation to the number of residents that can be accepted in the BLL for a particular experiment. Therefore, it is a time-consuming procedure to finish one experiment with a typical user and make space for future occupants to accomplish the same test. In other words, one of the main drawbacks of performing human-technology interaction studies in a living lab setting is the limited number of users involved. Small-scale experiment contributes to less number of feedbacks which might not be desirable; since many aspects of users are involved in the human-technology interaction and different groups of users must be under experiment such as different age groups, gender, and even people with different range of knowledge in terms of technology or environmental awareness. Besides, being perceived from different perspectives by a larger number of users, the technology is better examined in terms of its strengths and weaknesses.

Finally, in a controlled laboratory environment where all factors are kept constant to examine the effect of only one, problems and weaknesses related to that factor are more easily identified. This approach helps to understand the effect of one variable apart from the combination of others to provide more precise findings. For example in one of the case study living labs where residents complain about the low temperature on the ground level and high temperature on the upper floor, it was found that the problem was not related to the heating technology or the control system to regulate temperature, instead, it was due to the lack of porch in the entrance area and the layout design with an open staircase in the middle (Schulze, 2013). This makes researchers solve the problem by closing the staircase areas and adding a porch at the entrance. Therefore the second group of users did not complain about the same issue (Schulze, 2015). In contrast, if the experiment were carried out in users' private contexts, it was highly unlikely for the researchers to detect such problems easily since they did not have full control over different variables in different contexts. Apart from that, a particular defect in technology or system is seen by one group of users and the evolved version of the prototype will be experimented by future users. In this way, the technology is always under development in a controlled setting.

4-4. Findings and reflections from the questionnaire

The aim of the survey was to receive data about involving users in the LL experiment; the decision is made to select cases with an experience in human-technology interaction. Hence, public buildings such as office and educational facilities, as well as buildings where did not involve users in participation are excluded. 10 cases were selected to be included in the survey and this does not include 2 BLLs used in the full paper review. A list of the names and location of the living labs is available in Table 4-2. The questions are designed based on a reference survey conducted by TRAIL Living Lab in 2011, as well as the author's knowledge from the literature review and they are adopted particularly for this research purpose. The complete version of the questionnaire is available in an online repository[7].

BLL name	Location
Legacy Living Lab (L3)	Australia
Ripple House	U.S.
Refract House	U.S.
CNR-ITC ZEB Laboratory	Italy
BNZEB	Italy
Passivehaus Sicily	Italy
HSB living lab	Sweden
KTH Live-in-Lab (LiL)	Sweden
LOW3 prototype	Spain
Concept house village: delft prototype	Netherlands

Table 4- 2- Name and location of BLLs to send questionnaire

Before asking questions in the questionnaire, a general introduction regarding the aim of the research and the questions was provided. 30 questions were designed in 2 different sections 1) objectives and general features of the BLL, and 2) user-involvement methodologies. The format of the questions was close-ended with multiple-choice answers which were prepared on a Google drive and the link was provided in the email to send to recipients. The respondents were also asked to add their own comments if the answers do not cover their responses. At the end of the introduction, the respondents were asked to direct the email to the responsible person if they cannot answer the questions.

One of the main challenges in this questionnaire was the limited number of case studies that reduce the possibility of receiving sufficient answers. Being optimistic, the thought was to receive at least half of the answers so that it would be possible to draw some results. Sadly, only 2 BLLs answered the questions which made it impossible to make a conclusion by doing quantitative analysis. Yet, in this section, I will provide some reflections on lessons learned and the feedback received during this process.

Apart from the risk of receiving insufficient answers due to the online nature of the survey, finding the recipient's email address was also a problem. Since some BLLs were built more than 10 years ago, finding contact information for a LL manager or someone with comprehensive information about the building and related activities has been challenging. To find such information, the first effort was to visit the BLL web page. Regardless of being

[7] https://doi.org/10.5281/zenodo.6595603

active or inactive, nearly half of the cases had a particular website introducing the LL and its activities. For projects without websites, the second effort was looking at the literature to find relevant authors. Since many BLLs are affiliated with universities or academic institutions, it was possible to find a contact person among authors of literature. Besides, it became clear that a professor at the university is the responsible person for most of the BLLs. The third attempt was to search the name of the BLL on Google. This attempt was made when no contact information was found and no response was received after the first 2 rounds of sending the questionnaire. Since some companies introduce themselves as one of the partners of the project, it was likely to find some more information about the contact person on their websites.

After the first round of sending questionnaire, 2 responses were received. One, answered the questions, and another, redirected the email to the responsible person who also answered the survey. Several days later, a questionnaire was sent out for the second time to those who did not answer. In addition, newly found email addresses were added to this pool. 3 answers were received; 2 of them were related to one project, while redirected the email to the manager or the head of the research, which was finally unsuccessful. The last response gave some reasons of why it was impossible for them to answer. Therefore, in general, only 2 respondents filled out the questionnaire after 3 times effort by the author over 3 weeks.

Of course, there may be some reasons to receive such a small number of responses. Since the contact persons were mostly professors, probably they could not manage to find time for answering questions. For other cases, there is the possibility that the contact person did not have the capability to answer questions since they did not have enough information in detail. Also, there is the possibility that the number of projects which has been run in the building was high and it would be difficult to limit all related activities to one questionnaire.

One of the respondents[8] who filled out the questionnaire was very interested to receive the results of the survey. This can be a sign that participants want to see their impact on a scientific practice in which they are involved. Also, another respondent who was enthusiastic about LL research provided me with some suggestions for other LL research projects in which they were involved. He described his participation in the LL project[9] as “a great research and professional experience”.

[8] CNR-ITC ZEB Laboratory

[9] Passivehaus Sicily

Among feedbacks received from respondents, one[10] told that the intention was to answer the questions; however, it was not possible to complete the survey since their BLL has “a broad scope” and “they are an infrastructure, not a single project.” So they cannot answer questionnaire which has a single focus. This shows that BLLs with a higher level of flexibility cannot answer such questions. This is due to the fact that the building acts as a test-bed for implementing other projects. And the building itself is not considered as a project. In these types of facilities, the test environment changes according to the different requirements. However, the study found a conflict in this regard. Since the survey included 2 projects that labeled themselves as infrastructures (*CNR-ITC ZEB*) (*KTH LiL Infrastructure*), the reason that one answered the question and the other rejected may depend on the level of their flexibility and capability to implement different projects. Therefore, to understand partnership and user-involvement methodologies in “infrastructure” BLLs, similar projects must be included in the same pool, and a new set of questionnaire is needed to rate their level of flexibility and user involvement that can be considered for future research.

[10] KTH Live-in-Lab

4-5. Lessons learned

This chapter answered to the third group of research questions with the main question of: *RQ3: What are the best methodologies for effective user involvement in SBLL experiment?*
But in order to define proper methodologies during the experiment in LL, we should first define the answers to the sub-research questions as:

A) *What are the main indicators which affect SBLL experiment results?*
B) *What is the role of each indicator in the process of living lab success?*

The process of the research in this part starts by selecting 2 relevant case studies found in the systematic literature review, with user involvement methodologies. The answers to the sub-research questions are provided by reflecting on approaches employed for the LL experiments. In addition, because of the limitation of information available regarding case studies, relevant results found in other literature are included in the discussion to increase the validity of the findings. Since the answers to sub-research questions were intertwined, it was decided to discuss both of them at the same time. Therefore, the determinant factors which affect user engagement and their particular role in BLL experiments are provided in the next paragraphs.

<u>1-The method of introducing the concept to the users</u>: Before starting the experiment the concept should be communicated to the users. This includes introducing the concept at 2 different levels including a) introducing the concept of the building as the context of the experiment, and b) explaining the aim of implemented technologies inside of this context. Using methodologies that involve participants directly in the process and the users can experience the situation in person before the experiment will give the chance to researchers to study the users' actions and reactions by direct observation.

<u>2- Users' recruitment methodologies:</u> During the experiment participants have to test technologies and have to continue using them during a particular period of time in the LL. During this time, some participants lose their tendency for continuing the usage of technologies in various situations such as:

a) When the technology is too challenging for users and they become confused
b) When they face an issue during the application of the technology
c) When they see no benefit for using the technology

To reduce the challenges regarding the level of user involvement in the experiment, 2 main indicators should be identified including a) providing users with incentives before and during the experiment, as well as b) understanding the users' motivation for participation. The importance of these factors becomes more prominent when the experiment takes for long-term. For the first indicator, various incentives can be proposed to users which can be categorized as financial incentives, and non-financial incentives.

Using financial incentives have some challenges. It does not applied for many people; it cannot be used for long-term experiments, since users' financial motivation might be reduced after some time of the experiment. This motivation is only beneficial when users are testing technologies; and it does not affect participants who are involved in co-creation process since their intrinsic incentive is superior to a financial one. In contrast, non-financial incentives can encourage participants to continue the experiment more effectively since these incentives are of higher value for users. These types of motives can be defined as: providing a learning environment which is beneficial for users; putting attracting assignments for users as a reminder; informing them about their valuable role in the research and promising them to be aware of the final results.

To understand the motivation of users to participate, a multi-stage recruiting process based on qualitative and quantitative methods can be applied.

It is important to note that the criteria involved in the selection process should consider other aspects of the test, such as specific qualifications for users to test the technology.

3- Occupancy time for the experiment: This period of time must be defined based on several important factors such as considering:

a) A "honeymoon" period which is the time required to form a new attitude toward technology or to adapt to a new environment.

b) The level of complexity of the technologies in practice

c) The particular characteristics of users e.g. age, gender, etc.

4- The level of users' acceptance and satisfaction: Social, architectural, and engineering aspects of the BLL design affect the level of users' satisfaction and acceptance of the environment and implemented technologies. Considering the user-bond factors such as adaptability of technologies with aesthetics, comfort, and users' lifestyle is also crucial in users' satisfaction. The main important factor which reduces the risk of users' non-acceptance and dissatisfaction is to involve users in LL activities as co-creators at the early stage of design, rather than observing them as test users at the experimental phase. Also, the availability of the infrastructure required for technologies at a larger scale (e.g. charger for electric vehicles on an urban scale) is an indicator of the tendency of users for using the technology.

<u>5- Having an experimental character:</u> A quick comparison between BLLs and users' private houses used as experimentation context shows the concurrent cost and benefits of this setting. Some of the positive and negative points of these facilities are provided as follows:
-Users feel that they are always under observation and measurement; therefore they do not feel safe to illustrating their real attitude and realistic interaction toward technology.
-Since it costs nothing to the users, they use technologies as they prefer, regardless of the aim of the technology or the building.
-Since all factors are kept constant, issues regarding experimenting technologies can be identified more clearly.
However, a comprehensive study is required in this area to understand the position of BLLs in the process of technological innovation by a full comparison between various experimental contexts such as the laboratory setting, and in-situ experiments at the users' private place.

For answering to the main research question of this chapter, some brief guidelines are provided which are beneficial to increase the impact of user-involvement in the BLL experiment:

1- Introduce the experiment, technology, and building living lab as a test facility clearly to the users by involving them directly in the process.
2- Define a clear user selection methodology for each experiment based on the longitudinal of the study, users' properties, and qualifications required for the experiment, as well as understanding the incentive of applicants for participation.
3- Announce the aims and incentives of the experiment to the users clearly during recruitment process.
4- Providing proper incentives for the users to continue the experiment by considering the longitudinal of the study and the nature of the experiment. For LL projects with long-term co-creating nature, non-financial incentives are recommended.
5- Define a domain of occupancy time in BLL according to particular users' characteristics, and the complexity of the tasks. While considering the minimum required time for users' adaptation to new technology and the environment.
6- Try to increase the level of satisfaction of the users with the technology and the environment by involving users in co-creation process at the early design stage.

05. Conclusion and future research

At the NTNU campus there is a facility called “ZEB living lab”. I saw the picture of the building when I wanted to apply sustainable architecture from my home country, more than 2 years ago. I was curious to understand what the real function of this building is and how it acts. When I reached the NTNU campus and visit the building in person for the first time, I changed my question, asking why such buildings should be constructed at all when they do not have enough function as expected. Does it really worth building such an expensive facility as a living lab just to test technologies with some users? What makes these types of facilities different from normal laboratory settings or even testing technologies in users’ private places?

The concept of the thesis started with a big ambition which was to understand the necessity of “buildings” that act as “living laboratories”. The idea was to identify the spectrum of this phenomenon and to clarify some questions regarding the essence of the building and implemented methodologies. The research started with a very systematic literate review which constructs the backbone of the thesis. The use of comparative case studies and questionnaire was to understand methodologies regarding experimental practices in BLLs. During this process, the research has faced many challenges including the lack of information on different aspects of this topic, low numbers of feedback from the respondents of the survey, and time constraints of the thesis project, which was about 5 months, etc. All of these limitations did not let the final ambition be accomplished thoroughly. Yet, many aspects of this phenomenon have become clear which paves the way for future researchers and BLL practitioners. In addition, final results can be used as a kind of precaution when setting up experimental activities in BLL contexts.

Buildings as Living Labs comprise a variety of projects with different scales, concepts, functions, and capabilities. Some of them are built to have a particular function in addition to being a test-bed (e.g. office building). A number of them are constructed as a facility with a temporary function (e.g. single-family house) and their aim is to study the interface between users and technologies. Some others are not considered as common buildings. They are infrastructures or open platforms in which modules or building elements can be installed and removed easily. Hence, the term “Building Living Lab” has a broad meaning. Perhaps this is why no definition of this phenomenon has been provided in the literature so far.

Regarding environmental sustainability practices in BLLs, it is found that despite many projects created under this category with the BLL title, the number of literature covering different aspects of these buildings is very low. Take an example of the Solar Decathlon competitions. Every 2 years, many buildings from various countries participate in this competition; yet, only 3 projects have been found in literature in an incomplete and scattered way. Also, detailed information about the nature of collaboration and experimental activities within this type of facility is rare. BLLs with lots of effort, resources, and finance devoted to their construction, have had few outcomes in scientific databases. The issue becomes more apparent when considering the fact that more than two-thirds of the cases are from European countries while a continent such as Africa does not have any activity in this field. This leads to a biased measurement and evaluation of BLL activities since experiences and practices are reported mostly from European perspectives.

SBLLs can be considered as criteria for measuring environmental sustainability activities in different regions. They can be a sign of different countries' attention to environmental sustainability practices. The fact that Europe and North America are at the forefront of this field, explains their level of activities to accelerate the transition toward environmental sustainability goals. Even some countries such as the U.S. have started to use these facilities as a platform for educating such activities to their students.

The outcome of the BLL experiments includes the results of the interactions between decisions, methodologies, and practices even before the start of the experiment. Building environmental character (e.g. experimental, architectural, technological, etc.), users' physical (e.g. age, gender, etc.) and mental characteristics (e.g. motivation, adaptation, etc.), methodologies in use (user recruitment, communicating living lab objectives, data collection methods, interaction with users, etc.), occupancy time and etc. are so intertwined that it is almost impossible to separate one factor from another or to examine the effect of one factor separately. Hence, the study of human-technology interaction in BLL is a complicated and demanding process. And that may be the reason why no instructions have been provided for BLL experimental activities.

The potential of BLL as an approach to study technological innovations in a real-life context has been highlighted by literature. According to (Andersson & Rahe, 2017) technologies can be tested and evaluated during a 4 stepwise process. From normalized testing of the prototype in a normal laboratory setting to the improvement of human-technology interaction in living labs. Although BLL tries to create a physical setting to make the experiment closer to a real-life situation, there are still some doubts about the experimental and artificial character of the living lab, which does not let users illustrate their real intention and behavior regarding technologies. The amount of materials and resources used for constructing such test buildings as temporary use facilities is also under discussion. Therefore, there have been some suggestions to use users' private houses as an ideal experimental setting to test prototypes. But using an in-situ experimentation context has its own issue. One of the main challenges is that they do not provide a controllable environment. Hence, a comprehensive study is required in this area. It would be a good suggestion to understand the strengths, weaknesses, opportunities, and threats for different experimental settings. This can help researchers to realize which of these contexts are more beneficial for setting up the test environment according to their objectives. Then, by understanding the methods and practices in each environment, and with the help of a comparative perspective, best practices and methods can be selected from all environments to improve the drawbacks of an experimental setting such as the building living lab.

APPENDIX I

<table>
<tr><th colspan="4">Living lab name</th></tr>
<tr><td rowspan="7">Lab ID</td><td colspan="2">Location (country)</td><td></td></tr>
<tr><td colspan="2">Scale</td><td></td></tr>
<tr><td colspan="2">Areas</td><td></td></tr>
<tr><td colspan="2">Context</td><td></td></tr>
<tr><td colspan="2">Duration</td><td></td></tr>
<tr><td colspan="2">ENoLL</td><td></td></tr>
<tr><td colspan="2">Living lab methodological scale</td><td></td></tr>
<tr><td rowspan="6">Lab features</td><td colspan="2">Objective performance of LL</td><td></td></tr>
<tr><td rowspan="2">Real-life context</td><td>Built for LL purpose (test-bed)</td><td></td></tr>
<tr><td>Usability of LL context</td><td></td></tr>
<tr><td colspan="2">Thematic focus</td><td></td></tr>
<tr><td colspan="2">Entrepreneurial process</td><td></td></tr>
<tr><td colspan="2">General orientation of approach toward innovation</td><td></td></tr>
<tr><td rowspan="13">Type of Partnership</td><td colspan="2">Nature of collaboration:
Public/Private/ People partnership highlighted</td><td></td></tr>
<tr><td colspan="2">Type of Actors/stockholders</td><td></td></tr>
<tr><td colspan="2">The Level of cooperation</td><td></td></tr>
<tr><td colspan="2">Initiated by (naming)</td><td></td></tr>
<tr><td colspan="2">Main Actors</td><td></td></tr>
<tr><td rowspan="2">The way of collaboration</td><td>Digital</td><td></td></tr>
<tr><td>Traditional</td><td></td></tr>
<tr><td rowspan="4">Users</td><td>User involvement dimension</td><td></td></tr>
<tr><td>End users</td><td></td></tr>
<tr><td>Duration of experimentation</td><td></td></tr>
<tr><td>Numbers of users</td><td></td></tr>
<tr><td rowspan="2">The Governance model</td><td>Source of funding</td><td></td></tr>
<tr><td>Making profit</td><td></td></tr>
<tr><td rowspan="3">Lab Orientation toward sustainability</td><td colspan="2">Sustainability challenge to overcome</td><td></td></tr>
<tr><td colspan="2">Approach toward sustainability</td><td></td></tr>
<tr><td colspan="2">Applied tools & systems</td><td></td></tr>
</table>

APPENDIX II

Name, Location, the source of initiation, and nature of partnership in SBLLs

Living lab Name	Location	Initiated by	Nature of partnership
Legacy Living Lab (L3)	university campus	Academia: Curtin University	Industry, academia
Ripple House	university campus	Academia: Sanata Clara university	…….
Refract House	university campus	Academia: Sanata Clara university	....
Solar XXI Building Living lab	National Energy & Geology laboratory campus (LNEG)	National Energy & Geology laboratry (LNEG)	....
The Fraunhofer-inHaus 1 (Smart Home lab)	in the vicinity of Fraunhofer IMS and the University of Duisburg	Fraunhofer Institute for Microelectronic Circuits and Systems IMS	....
Bellevue Building living lab	university campus	…………..	Quadruple helix: PPPP
Efficiency-House-Plus with Electric Mobility	federal agency for the real state	The Federal Ministry of Transport, Building and Urban Development (BMVBS)	....
OU44	university campus	…………….	Industry, academia
GreEn-ER Living Lab	university campus	…………….	Public-Private Partnership (PPP)
The Eco_Wall project	university campus	Academia: Porter school of environmental studies	………
ASHRAE's Living Lab	Ashrae headquarters	Ashrae foundation	....
The Living Lab smart Home (FZI)	FZI Research Center for Information Technology	The FZI Research Center for Information Technology in Karlsruhe, Germany	....
The LOW3 prototype solar house of UPC	university campus	Academia: the Solar Research Centre (CISOL) of the Vallès School of Architecture (ETSAV) of UPC-Barcelona Tech	Public Private Partnership: Collaboration between academia, companies and research entities but also local administration
Concept House prototype 1 by Delft University	urban context	…………….	Quadruple helix: PPPP
HSB Living Lab	university campus	Johanneberg Science Park, HSB and Chalmers	Industry, academia, society
Coventry University as a living lab	university campus	………..	....
ZEB LIVING LAB	university campus	NTNU and SINTEF	Students, researchers and, industry partners
eLUX living lab at the University of Brescia	university campus	Energy Laboratory at University Expo is the Health & Wealth laboratory of the University of Brescia	....
Passivehaus Sicily Botticelli project	urban context	………..	....
Toyota Dream House (PAPI)	Urban context/ near Toyota museum	TRON project leader Ken Sakamura, in cooperation with Toyota Home K.K.	....
Joyce Centre for Partnership and Innovation (JCPI) building	university campus	Academia: Mohawk College	………
“Benevento” Nearly Zero Energy Building BNZEB	university campus	Academia: university	Quadruple helix: PPPP
ZEB lab	university campus	SINTEF & NTNU	Co-creation between R&D environments, public actors and leading contractors
CNR-ITC ZEB Laboratory	......	construction technologies institute, national research council of Italy	Quadruple helix: PPPP

References

Akashi, O., & Hanaoka, T. (2012). Technological feasibility and costs of achieving a 50% reduction of global GHG emissions by 2050: mid-and long-term perspectives. *Sustainability Science*, *7*(2), 139-156.

Alahmad, M., Pfannenstiel, M., Alvine, D., & Waters, C. (2007). Education and Industry, a Union to Facilitate Engineering Learning. 2007 Annual Conference & Exposition,

Almirall, E., & Wareham, J. (2011). Living Labs: arbiters of mid-and ground-level innovation. *Technology Analysis & Strategic Management*, *23*(1), 87-102.

Alwaer, H., & Clements-Croome, D. (2010). Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings. *Building and environment*, *45*(4), 799-807.

Andersson, S., & Rahe, U. (2017). Accelerate innovation towards sustainable living: exploring the potential of Living Labs in a recently completed case. *Journal of Design research*, *15*(3-4), 234-257.

The Aware Home Research Initiative. Retrieved 18th March from https://awarehome.imtc.gatech.edu/drupal/?q=content/about-ahri

Ballon, P., Pierson, J., & Delaere, S. (2005). Test and experimentation platforms for broadband innovation: Examining European practice. *Available at SSRN 1331557*.

Berardi, U. (2013). Clarifying the new interpretations of the concept of sustainable building. *Sustainable cities and society*, *8*, 72-78.

Beutel, T., Jonas, J. M., & Moeslein, K. M. (2017). Co-creation and user involvement in a living lab: an evaluation of applied methods. Proceedings der,

Bhavsar, R., Cupido, A., & Arriaga, M. (2020). Mohawk college's net zero energy and zero carbon building—a living lab for high efficiency and renewable energy technologies in buildings. *Journal of Green Building*, *15*(1), 185-214.

Breadsell, J., & Minunno, R. (2021). How can Universities Transition to Net Zero? Building a Future towards Global Net Zero,

Bryman, A., Bell, Emma. (2011). *Business Research Methods*. OXFORD University Press.

Carlson, L. E., & Brandemuehl, M. J. (1997). A living laboratory. 1997 Annual Conference,

Clements-Croome, D. (2011). Sustainable intelligent buildings for people: A review. *Intelligent Buildings International*, *3*(2), 67-86.

CNR-ITC ZEB Retrieved May 2nd from https://www.itc.cnr.it/laboratorio-zeb-uninfrastruttura-di-ricerca-e-sviluppo-a-servizio-delle-imprese/?lang=en

Compagnucci, L., Spigarelli, F., Coelho, J., & Duarte, C. (2021). Living Labs and user engagement for innovation and sustainability. *Journal of Cleaner Production*, *289*, 125721.

Coorevits, L., Georges, A., & Schuurman, D. (2018). A framework for field testing in living lab innovation projects. *Technology Innovation Management Review*, *8*(12), 40-50.

Cory, J. (2010). THE ECO_WALL CHALLENGES IN THE PURSUE OF LEED PLATINUM. Proceedings: CESB 2010-Central Europe towards Sustainable Building 'From Theory to Practice,

Cui, A. S., & Wu, F. (2016). Utilizing customer knowledge in innovation: antecedents and impact of customer involvement on new product performance. *Journal of the academy of marketing science*, *44*(4), 516-538.

Curtis, S. (2015). An investigation of living labs for sustainability. Reflections on the living lab methodology. *Applied Research in Sustainable Consumption and Production (ARSCP) Master of Science in Environmental Management and Policy Lund, Sweden*.

Danza, L., Belussi, L., Barozzi, B., Bellazzi, A., Devitofrancesco, A., Depalma, M., Guazzi, G., Meroni, I., Maffè, C., & Ghellere, M. (2019). I-ZEB: Design and Development of a ZEB Test-Laboratory for an Integrated Evaluation of Building Technologies. IOP Conference Series: Earth and Environmental Science, Delinchant, B., Wurtz, F., Ploix, S., Schanen, J.-L., & Maréchal, Y. (2016). GreEn-ER living lab: A green building with energy aware occupants. 2016 5th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS),

Dourish, P. (2003). The appropriation of interactive technologies: Some lessons from placeless documents. *Computer Supported Cooperative Work (CSCW)*, *12*(4), 465-490.

Eekhout, M., & van Timmeren, A. (2016). *Development and Realisation of the Concept House 'Delft'Prototype: An Example of a Collaborative Concept Development for Energy Positive Apartments* (Vol. 13). IOS Press.

Elfstrand, P., Morrison, G. M., Toups, L., & Hagy, S. (2017). The storyline for the design process that shaped the HSB Living Lab. In *Living Labs* (pp. 113-129). Springer.

Esposito, R., Fiorini, L., Limosani, R., Bonaccorsi, M., Manzi, A., Cavallo, F., & Dario, P. (2016). Supporting active and healthy aging with advanced robotics integrated in smart environment. In *Optimizing assistive technologies for aging populations* (pp. 46-77). IGI Global.

Eysenbach, G. (2005). The law of attrition. *Journal of medical Internet research*, *7*(1), e402.

Femenías, P. (2014). Defining challenges for future sustainable homes: A review of earlier experimental activities. ARCC Conference Repository,

Femenías, P., & Hagbert, P. (2013). The habitation lab: Using a design approach to foster innovation for sustainable living. *Technology Innovation Management Review*, *2013*(November), 15-21.

Finocchiaro, L., Goia, F., Grynning, S., & Gustavsen, A. (2014). The ZEB Living Lab: a multi-purpose experimental facility. Paper for Gent Expert Meeting, April,

Flammini, A., Pasetti, M., Rinaldi, S., Bellagente, P., Ciribini, A., Tagliabue, L., Zavanella, L., Zanoni, S., Oggioni, G., & Pedrazzi, G. (2018). A living lab and testing infrastructure for the development of innovative smart energy solutions: The eLUX laboratory of the University of Brescia. 2018 AEIT International Annual Conference,

Flavin, M. (2012). Disruptive technologies in higher education. *Research in Learning Technology*, *20*.

Fraunhofer inHaus – research for the future of living. Retrieved 15 February from http://www.vaillant.info

FZI Living Lab smartHome/AAL. Retrieved 15 February from https://www.fzi.de/en/fzi-house-of-living-labs/

Georges, A., Schuurman, D., & Vervoort, K. (2016). Factors affecting the attrition of test users during living lab field trials. *Technology Innovation Management Review*, 35-44.

GhaffarianHoseini, A., Dahlan, N. D., Berardi, U., GhaffarianHoseini, A., & Makaremi, N. (2013). The essence of future smart houses: From embedding ICT to adapting to sustainability principles. *Renewable and Sustainable Energy Reviews*, *24*, 593-607.

Greve, K., Leminen, S., De Vita, R., & Westerlund, M. (2020). Unveiling the diversity of scholarly debate on living labs: A bibliometric approach. *International Journal of Innovation Management*, *24*(08), 2040003.

Hasche, N., Höglund, L., & Linton, G. (2020). Quadruple helix as a network of relationships: creating value within a Swedish regional innovation system. *Journal of Small Business & Entrepreneurship*, *32*(6), 523-544.

Haukipuro, L., Väinämö, S., & Hyrkäs, P. (2018). Innovation instruments to co-create needs-based solutions in a living lab. *Technology Innovation Management Review*, *8*(5).

Herssens, J., Nijs, M., & Froyen, H. (2014). Inclusive Housing (Lab) for All: a home for research, demonstration and information on Universal Design (UD). *Assistive technology research series*, *35*, 185-194.

Huang, J. H., & Thomas, E. (2021). A Review of Living Lab Research and Methods for User Involvement. *Technology Innovation Management Review*, *11*(9/10).

Hugé, J., Waas, T., Dahdouh-Guebas, F., Koedam, N., & Block, T. (2013). A discourse-analytical perspective on sustainability assessment: interpreting sustainable development in practice. *Sustainability Science*, *8*(2), 187-198.

Industry, B. T. (2003). Sustainable building and construction: facts and figures. *Ind Environ*, *26*(2-3), 5-8.

Intille, S. S., Larson, K., Beaudin, J., Tapia, E. M., Kaushik, P., Nawyn, J., & McLeish, T. J. (2005). The PlaceLab: A live-in laboratory for pervasive computing research (video). *Proceedings of PERVASIVE 2005 Video Program*.

Intille, S. S., Tapia, E. M., Rondoni, J., Beaudin, J., Kukla, C., Agarwal, S., Bao, L., & Larson, K. (2003). Tools for studying behavior and technology in natural settings. International Conference on Ubiquitous Computing,

Jarnagin, R. E. (2008). ASHRAE's living lab. *ASHRAE Journal*, *50*(10), 12.

Korsnes, M., Berker, T., & Woods, R. (2016). Compliance and Deviation: How occupants interact with a high performance zero emission building. DEMAND Centre Conference,

Korsnes, M., Berker, T., & Woods, R. (2018). Domestication, acceptance and zero emission ambitions: Insights from a mixed method, experimental research design in a Norwegian Living Lab. *Energy Research & Social Science*, *39*, 226-233.

KTH LiL Infrastructure. Retrieved May 2nd from https://www.liveinlab.kth.se/infrastruktur

KTH live-In lab. KTH Univeristy. Retrieved 01 April from https://www.liveinlab.kth.se/

Leminen, S., & Westerlund, M. (2012). Towards innovation in Living Labs networks. *International Journal of Product Development*, *17*(1-2), 43-59.

Leminen, S., & Westerlund, M. (2019). Living labs: From scattered initiatives to a global movement. *Creativity and Innovation Management*, *28*(2), 250-264.

Leminen, S., Westerlund, M., & Nyström, A.-G. (2012). Living Labs as open-innovation networks.

Liedtke, C., Geibler, J. v., & Baedeker, C. (2012). The" sustainability living lab" as a reflexive user-integrating research infrastructure. In: Proceedings of the 3rd International Conference on Sustainability Transitions, August 29th-31st 2012, Lyngby, Denmark; Track E.

Liedtke, C., Welfens, M. J., Rohn, H., & Nordmann, J. (2012). LIVING LAB: user-driven innovation for sustainability. *International journal of sustainability in higher education*.

Lloyd, P., & Deasley, P. (1998). Ethnographic description of design networks. *Automation in construction*, *7*(2-3), 101-110.

Logghe, S., Baccarne, B., & Schuurman, D. (2014). An exploration of user motivations for participation in Living Labs. ISPIM Conference Proceedings,

Marckmann, B., Gram-Hanssen, K., & Christensen, T. H. (2012). Sustainable living and co-housing: evidence from a case study of eco-villages. *Built Environment*, *38*(3), 413-429.

Masseck, T. (2017). Living labs in architecture as innovation arenas within higher education institutions. *Energy Procedia*, *115*, 383-389.

Mastelic, J., Emery, L., Previdoli, D., Papilloud, L., Cimmino, F., & Genoud, S. (2017). Energy management in a public building: A case study co-designing the building energy management system. 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC),

O'Brien, W., Doré, N., Campbell-Templeman, K., Lowcay, D., & Derakhti, M. (2021). Living labs as an opportunity for experiential learning in building engineering education. *Advanced Engineering Informatics*, *50*, 101440.

Pallot, M., & Pawar, K. (2012). A holistic model of user experience for living lab experiential design. 2012 18th International ICE Conference on Engineering, Technology and Innovation,

Pasman, G., Stappers, P. J., Hekkert, P., & Keyson, D. (2005). The ID-studiolab 2000-2005. *Proceedings of Design Research in the Netherlands*, *2005*.

Romero Herrera, N. (2017). The emergence of living lab methods. In *Living Labs* (pp. 9-22). Springer.

Ruyter, B. d., Aarts, E., Markopoulos, P., & Ijsselsteijn, W. (2005). Ambient intelligence research in homelab: Engineering the user experience. In *Ambient Intelligence* (pp. 49-61). Springer.

Sanders, E. B.-N., & Stappers, P. J. (2012). *Convivial toolbox: Generative research for the front end of design*. Bis.

Schaffers, H., & Kulkki, S. Living labs, An Open Innovation concept fostering rural development. Asia-Pacific Tech Monitor, September 2007. In.

Schulze, E., Wilbrandt, A, Dietel, K, Austria, D. *Socio-scientific monitoring of life in the Efficiency House Plus with electromobility*. ZUKUNFT BAU. Retrieved 15 April from https://www.zukunftbau.de/effizienzhaus-plus/forschung/begleitforschung-bmub-haus/sozialwissenschaftliches-monitoring

Schulze, E., Wilbrandt, A., Dietel, K., Austria, D. (2013). *Socio-scientific monitoring of the Efficiency House Plus with Electromobility* (No.3). B. I. f. S. Research.

Schulze, E., Wilbrandt, A., Dietel, K., Austria, D. (2015). *Socio-scientific monitoring of the Efficiency House Plus with Electromobility* (No.4). B. I. f. S. Research.

Schuurman, D., De Marez, L., & Ballon, P. (2015). Living Labs: a systematic literature review. *Open Living Lab Days 2015*.

Schuurman, D., Lievens, B., De Marez, L., & Ballon, P. (2012). Towards optimal user involvement in innovation processes: A panel-centered Living Lab-approach. 2012 Proceedings of PICMET'12: Technology Management for Emerging Technologies,

Scott, K., Quist, J., & Bakker, C. (2009). Co-design, social practices and sustainable innovation: involving users in a living lab exploratory study on bathing. Proceedings of Paper for the “Joint Actions on Climate Change” Conference, Aalborg, Denmark,

Seo, E., Bae, S., Choi, H., & Choi, D. (2021). Preference and usability of Smart-Home services and items-A Focus on the Smart-Home living-lab–. *Journal of Asian Architecture and Building Engineering*, *20*(6), 650-662.

Skeie, K., Korsnes, M., & Woods, R. (2019). Reanalysis of occupant experiment in ZEB Living Lab. IOP Conference Series: Earth and Environmental Science,

Solar Decathlon. Retrieved 07/03 from https://www.scu.edu/engineering/centennial/stories/research-and-academics/solar-decathlon/

Solar Decathlon. U.S. Department of Energy. Retrieved 08 April from https://www.solardecathlon.gov/about.html

Spohrer, J. C., & Freund, L. E. (2012). *Advances in the human side of service engineering*. CRC Press.

Ståhlbröst, A. (2008). *Forming future IT: the living lab way of user involvement* Luleå tekniska universitet].

Ståhlbröst, A., & Bergvall-Kåreborn, B. (2011). Exploring users motivation in innovation communities. *International Journal of Entrepreneurship and Innovation Management*, *14*(4), 298-314.

Ståhlbröst, A., & Holst, M. (2017). Reflecting on actions in living lab research. *Technology Innovation Management Review*, *7*(2), 27-34.

Strategies for Efficiency Houses Plus: Principles and examples of energy-generating buildings. (2016). N. C. Federal Ministry for the Environment, Building and Nuclear Safety of Germany (BMUB).

This is NEST. Retrieved 2 April from https://www.empa.ch/web/nest/aboutnest

Time, B., Engebø, A., Christensen, M., Dalby, O., & Kvande, T. (2019). The design process for achievement of an office living laboratory with a ZEB standard. IOP Conference Series: Earth and Environmental Science,

Veeckman, C., Schuurman, D., Leminen, S., & Westerlund, M. (2013). Linking living lab characteristics and their outcomes: Towards a conceptual framework. *Technology Innovation Management Review*, *3*(12 december), 6-15.

Von Geibler, J., Erdmann, L., Liedtke, C., Rohn, H., Stabe, M., Berner, S., Leismann, K., Schnalzer, K., & Kennedy, K. (2014). Exploring the Potential of a German Living Lab Research Infrastructure for the Development of Low Resource Products and Services. *Resources*, *3*(3), 575-598. https://www.mdpi.com/2079-9276/3/3/575

WCED, S. W. S. (1987). World commission on environment and development. *Our common future*, *17*(1), 1-91.

Westerlund, M., & Leminen, S. (2011). Managing the challenges of becoming an open innovation company: experiences from Living Labs. *Technology Innovation Management Review*, *1*(1).

Wong, A. J., Gonza´ lez, J. E., Escobar, S., & Aschheim, M. (2010). On the Overall Energy Efficiency of a High-Performance Solar Energy Residential Building. ASME International Mechanical Engineering Congress and Exposition,

Woods, R., & Korsnes, M. (2019). Homemaking in a Living Laboratory: Interpretations of a Zero Emission Housing Solution. *Home Cultures*, *16*(2), 135-155.

ZEB Living Lab. SINTEF. Retrieved 16 April from https://www.sintef.no/alle-laboratorier/living-lab/