Teaching Sustainability - *Living Labs* in Architecture

A framework proposal for *Living Lab eco-systems* for teaching, research and innovation in the field of sustainable architecture and ESD in higher education.
Specific case study: Living Lab LOW3 (UPC – BarcelonaTech)

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ABSTRACT

Society finds itself today in need of transition towards a low-carbon and post-fossil era, and is obliged to search for alternatives to a production and consumption system based on a fossil-nuclear energy system and an extractive production system, which are incompatible with the earth's limited resources and the constraints of its biosphere.
The sector of most specific weight in energy consumption in the industrialized world is the building sector, which is responsible for almost half of all energy consumption of society today. This fact requires a deep change in the design of buildings, materials, systems and technologies, and also its concepts of use directly related to the life style of society, which should be changed holistically towards a model of much less environmental impact.
This complex and holistic transformation process needs education, knowledge generation, research and innovation for change. Once the fields of action, priorities and goals are defined, the question is where and how the processes which lead society to the necessary change, can be generated, and which are the places, tools, methodologies and strategies for an efficient synergy between education, research and innovation for change.
Higher education, universities and especially schools of architecture, have an important role and a specific potential in this context. New forms of teaching and learning, fostering specific SD related competences through experience-based and participatory learning processes with a holistic, pluridisciplinary view on sustainability, can strengthen their role in this transition process.
New approaches in the field of research and innovation, like open innovation processes and Living Lab ecosystems, can overlap with these advanced SD related teaching and learning activities to benefit mutually from generated synergies.
The present work has its origin in more than 10 years of teaching and research activity by the author in the field of sustainable architecture and solar energy, with a constant search for innovative forms of holistic experience-based education, lately focused on the implementation of a Living Lab for sustainable architecture and lifestyle at UPC. These practice-based approaches have generated the authors' motivation for deep theoretical research on education for sustainability and Living Labs for innovation, focused on the discipline of Architecture.

Based on these premises, the following hypothesis has been established:
Living Labs in Architecture can be efficient tools for teaching and learning about SD at universities, with a focus on sustainable architecture and life style, besides their important role as infrastructures for applied research and collaborative innovation between university, companies and society.

As knowledge dissemination tools and activities platforms they can contribute to ESD, HEI's SD transitions and the SD outreach of university, fostering holistically the paradigm shift of society towards sustainability.

In order to conduct this research, theoretical and practical approaches have been combined.

In the **first part** theories of ESD and the phenomena of Living Labs in architecture are reviewed:

- State of the Art analysis of education for sustainable development (ESD) and definition of key fields and competences for ESD in architectural education.
- Analysis of the Living Lab concept and approximation to the concept of Living Labs in Architecture.

In the **second part,** case studies are presented in order to understand the historical development of prototype architecture related to research and teaching in sustainability and the recent appearance of Architecture Living Labs:

- Review of 25 historical case studies of architecture laboratories and prototypes
- Review and analysis of 20 selected case studies of recent Architecture Living Labs

In the **third part,** similarities between the frameworks of ESD and Architecture Living Labs are identified and a classification and benchmarking tool for related projects is developed:

- Framework proposal for Architecture Living Labs in Higher Education Environments regarding Education for Sustainable Development (ESD).
- Development of a classification and benchmarking tool for Living Labs in architecture in order to analyze and visualize their specific characteristics and allow an approximation to the individual concepts.

In the **fourth part,** the specific case study of Living Lab LOW3, an action research project at ETSAV (UPC) directed by the author, is documented and evaluated:

- Description and analysis of the Living Lab LOW3 project, as a specific case study of an Architecture Living Lab for sustainability education at ETSAV (UPC)
- Evaluation of the specific case study and its contribution to a holistic education for sustainability at ETSAV (UPC).

The overall objective is to contribute to the understanding of the role which Living Lab projects can have in architecture, for the necessary shift towards a participative and transdisciplinary educational model in the EHEA, which brings together theory and practice, teaching, research and innovation, fostering a holistic transition towards a more sustainable society.

The major findings of this work are the followings:

- Living Labs encompass diverse projects or initiatives, which have in common specific characteristics, but differ widely in applied methodologies and tools according to their objectives, stakeholders and context among many other factors.
- Tools for their classification can contribute to the understanding of their characteristics and potential in different disciplines e.g. architecture as well as in a specific context like higher education and ESD.
- ESD education for architects and related disciplines benefit deeply from the concept of Living Labs in architecture as this type of project allows the application of specific teaching and learning methodologies, which foster ESD skills and abilities and competences.
- Field studies of Living Lab projects in architecture show a series of strengths and weaknesses of the concept regarding organization and management, integration into the established academic settings or sustainability of projects over time, which need to be addressed and overcome in order to integrate more widely Living Labs as educational tools in HE.

The original contribution to knowledge of this work is a structured review, analysis, classification and benchmarking of historical and recent Living Labs in Architecture for their better understanding, development and use as efficient tools for teaching, learning and innovation in

the field of sustainability. Several frameworks are developed, contributing to a better understanding of the role of Living Labs for ESD in the special context of Higher Education Institutions and the discipline of Architecture. A classification and benchmarking tool is proposed for a structured analysis and comparison of Living Lab projects related to ESD in HEIs. Living Lab LOW3 as specific Living Lab action research project at ETSAV (UPC) is documented and analyzed in order to gain insight in an experience-based approach to Living Labs in Architecture.

This thesis is organized as follows:

Chapter 1 gives a general introduction into **Education for Sustainable Development (ESD) in Higher Education** and the meaning of **Sustainability Education in the field of architecture**. A first introduction into the **phenomena of Living Labs in architecture** is given and **research questions** are raised, defining the **limitation of the research work** and describing the **applied research methodologies** as well a general outline of the present work.

Chapter 2 introduces the **terminology of Education for Sustainable Development (ESD),** its origins and its specific goals in the **field of architecture** as defined today. Learning outcomes and key competences for ESD as well as strategies for implementation of ESD in Higher Education Institutions are discussed.

Chapter 3 introduces the term Living Lab, the origin and definition of the concept, its conceptual framework and the current state of the art of this relatively new approach to innovation through participation and co-creation. Furthermore, it offers a specific interpretation of the concept in the **field of Architecture**.

Chapter 4 offers a review of **25 important case studies of architecture laboratories and prototypes**, introducing the historical development from prototype solar architecture to the specific approach of Living Labs today. Furthermore **20 selected case studies of recent Architecture Living Labs** are described and analyzed in detail.

Chapter 5 analyses the **role of Architecture Living Labs in Higher Education Environments regarding Education for Sustainable Development (ESD)** through a detailed comparison of the different concepts, methodologies and approaches.

Chapter 6 focuses on the development of a **parameter-based approach for the differentiation of Living Lab initiatives in architecture**. In a 3-step process, criteria of differentiation, methodology of descriptors and indicators and a graphic representation tool are developed and applied to selected case studies of recent Living Lab initiatives of chapter 4.

Chapter 7 describes the **case study of the LOW3 prototype solar house** of UPC BarcelonaTech and the process of its development, implementation and operation a**s Living Lab LOW3 during the period of 2010-2015**. It analyses the implemented Living Lab concept, its innovative approach to teaching, and its specific contributions to ESD at the ETSAV School of Architecture (UPC), using educational research methodology, namely action research, in order to document outcomes and results.

Chapter 8 offers general conclusions of the research done with specific focus on the potential of the Living Lab concept for ESD in the field of architecture and the developed proposal for a classification methodology of living labs in architecture. It concludes with a description of further fields of research, a final outlook and recommendations.

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"In the coming decades, the survival of humanity will depend on our ecological literacy – our ability to understand the basic principles of ecology and to live accordingly. This means that Eco literacy must become a critical skill for politicians, business leaders, and professionals in all spheres, and should be the most important part of education at all levels – from primary and secondary schools to colleges, universities, and the continuing education and training of professionals."

Fritjof Capra, "The New Facts of Life," 2008

"Not everything that counts can be measured. Not everything that can be measured counts."

Albert Einstein

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1 INTRODUCTION

1.1 Motivation

The present thesis has its origins in the authors' activities in the field of teaching and research of solar energy in buildings at the Vallès School of Architecture (ETSAV) of Universitat Politècnica de Catalunya (UPC), which started more than 10 years ago. In 2008 the author initiated and directed the first Solar Decathlon project of UPC, leading a team of 100 students and 50 companies in a 2-year process of the design, construction and operation of the energy self-sufficient solar house LOW3. This unique and transformational teaching and learning experience (for all student participants, but also for the author) led to the author's conviction that experience-based, collaborative and transdisciplinary project-based learning in non-formal learning environments is highly effective and deeply necessary in the education of future architects, offering immense possibilities for a disciplinary as well as holistic approach to sustainability in teaching and learning.

With the aim to maintain and foster the many positive energies generated by the LOW3 project, the author proposed, designed and implemented LOW3 as *Living Lab for Sustainable Architecture and Lifestyle* at the ETSAV campus at Sant Cugat del Vallès (Barcelona) from 2010 until today.

Nevertheless, the term Living Lab, its concepts, its application in the field of architecture, and its relation to sustainability education were not clear right from the start. This lack of an established conceptual framework motivated 5 years of theory and action research activities, which sustain and compose the present work, and which hopefully will be useful for similar projects and initiatives in the future.

1.2 Education for Sustainable Development (ESD) in Higher Education

Society finds itself today in a need for transition towards a low-carbon and post-fossil era, and is obliged to search for alternatives to a production and consumption system based on a fossil-nuclear energy system and an extractive production system, which have shown to be incompatible with the earth's limited resources and the constraints of its biosphere.
Since the Club of Rome commissioned report "The Limits to Growth" (Meadows et al. 1972) which analyzed the relevant data for the first time through computer modeling, and predicted that global resource consumption and production would 'overshoot', using resources beyond the carrying capacity of the planet; more than 40 years have now passed without finding a sound solution to the ever more complex and urgent challenge of sustainability.

UNESCO conferences have drawn attention to the importance of sustainable development of society for decades, with the first of these conferences, the 1968 UNESCO Intergovernmental Conference also called *the Biosphere Conference* (UNESCO 1993), and the 1972 Stockholm United Nations Conference on Human Environment, opening up the international focus on environment, development and sustainability.

The term *Sustainable Development* itself was officially introduced in 1987 by the World Commission on Environment and Development's report "Our Common Future"[1], also called the *Brundtland Report*, with the generic but well accepted statement that "humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations 1987)

The 1992 United Nations Conference on Environment and Development (UNCED), better known as the *Rio Earth Summit*, and the resulting "Declaration of Rio on Environment and Development"[2] have been an important step forward in this process, resulting in the Agenda 21 program for action to be taken globally, nationally and locally by organizations of the UN, governments, and major groups of the civil society. Within Agenda 21 and its 40 chapters education is a crosscutting theme, with chapter 36 "Education, Awareness and Training"[3] putting main focus on reorienting education towards sustainable development.

Beyond environmental education or education for sustainability, education for sustainable development (ESD) means more than the teaching of knowledge or principles in this context, namely an education for a holistic societal transformation towards a more sustainable future, with a broad focus on aspects like intergenerational equity, gender equity, peace, tolerance, poverty reduction, environmental preservation and restoration, natural resource conservation, and social justice. (UNESCO 2012)

The recently finished UN Decade of Education for Sustainable Development (DESD 2005-2014) has been declared under the premise "that education for sustainable development will contribute to enabling citizens to face the challenges of the present and future and leaders to make relevant decisions for a viable world." (UNESCO 2005a)

The resource-centered view of "The Limits to Growth" on global sustainability has been further developed since the early 1990's by other significant contributions in the field of production and consumption, like the ones originated by the Factor 10 Club[4], an international body of senior government, non-government, industry, and academic leaders working out of Germany's Wuppertal Institute, claiming for and fostering the development of concepts for an up to tenfold dematerialization of products and services.
Corresponding research has introduced new accounting systems like MIPS (Material Input per Service Unit) or the so-called "Ecological Rucksack" in order to measure the related grey energy input of products or services since the mid 1990's. (Lettenmeier et al. 2009) This led to a new understanding of our production and consumption systems and allows measuring the complex processes which lie behind these, in order to quantify and reduce the related environmental impact.

The most radical approach in this resource-centered research and debate regarding sustainability is the concept of a circular economy, based on considerations of industrial ecology, where two types of material flows are differentiated: biological nutrients which re-

[1] http://www.un-documents.net/our-common-future.pdf (accessed July 2015)
[2] http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm (accessed June 2015)
[3] http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=52&ArticleID=4415&l=en (accessed July 2015)
[4] http://www.factor10-institute.org/about.html#factor10_club (accessed June 2015)

enter the biosphere after use, and technical nutrients which circulate again and again without entering the biosphere.
Michael Braungart and William McDonough describe this *cradle-to-cradle* process as an imitation of nature with its closed nutrient flow and metabolism, a system approach where the concept of waste does not exist. (McDonough & Braungart 2002)

Beyond pure considerations of material flow or resource use and intensity, nowadays many other environmental, socio-economic and political aspects have gained importance in the process of finding our way towards a holistically sustainable society under a global perspective: the need for energy democracy, the importance of eco-literacy, the impact of the Internet on sustainability, and behavior and value changes for the adoption of more sustainable lifestyles, are priority fields of action in order to limit the effects of unsustainability like climate change, inequality, species loss and general environmental degradation. (The Worldwatch Institute 2015)
In consequence sustainability is not a single concept or solution to a single limited problem regarding for example population growth, energy and materials use, agriculture, health, or trade policy, but a complex process of transformation of our society, which depends on a shift towards a new set of values and profound system changes.

UNESCO describes Sustainable Development as a "constantly evolving concept, is thus the will to improve everyone's quality of life, including that of future generations, by reconciling economic growth, social development and environmental protection*."*(UNESCO, 2005a, par 1)
This broad vision reflects not only that there must be a common goal across nations and continents in order to be successful, but that each society needs to develop its own context related and cultural embedded approach to sustainability, as

> *"improving the quality of life takes on a different aspect from one continent to another, from one region to another, and from one country to the next. No single continent, government, institution or individual, however, can attain this alone because the nature of the challenges to overcome requires a global, collective, and individual commitment."* (UNESCO 2005a)

All these complex challenges related to sustainable development cannot be solved without the generation of a whole set of new knowledge, attitudes and values within society. Education and knowledge generation for SD must be therefore a societal priority, as *ESD* "is far more than teaching knowledge and principles related to sustainability. ESD, in its broadest sense, is education for social transformation with the goal of creating more sustainable societies." (UNESCO 2012)

In order to generate the necessary frameworks, methodologies and specific knowledge for ESD on the highest level through research and innovation, and due to the important role of Higher Education Institutions (HEIs) in the education of future professionals, thinkers and leaders of society, fostering ESD in Higher Education has been identified as a priority within the overall societal effort for SD.

ESD in Higher Education

Many international commitments and declarations have been generated since the 1990's, with the aim to foster and further develop ESD in general and ESD in Higher Education in particular.
The Talloires Declaration[5] (1991) and the COPERNICUS University Charter for Sustainable Development[6] (1993) have been main documents, through which several hundred universities committed themselves to promote education for sustainability.
Declarations like the Lüneburg Declaration (2001)[7] Barcelona Declaration (2004), Graz Declaration (2004)[8], Bonn Declaration (2009)[9] and lately the Rio +20 treaty on Higher Education (2014)[10], regarding the introduction of ESD into curriculum and the institutional frameworks of higher education institutions, show the continuous work in progress among universities and institutions in order to make ESD essential part of the HE system.

HEIs are important stakeholders in the process of sustainable transformation of society on three levels: on the organizational level as community with a specific practice, infrastructure and impact, through their academic activities in the field of teaching, research and innovation, and through its outreach to society, and as stakeholder in learning and transformation processes, contributing through knowledge for action or generating direct impact through activities.
Cortese (2003) states regarding the role of higher education in creating a sustainable future, that

> "*the educational experience of graduates must reflect an intimate connection among curriculum and (1) research; (2) understanding and reducing any negative ecological and social footprint of the institution; and (3) working to improve local and regional communities so that they are healthier, more socially vibrant and stable, economically secure, and environmentally sustainable."* (Cortese, 2003, p 18)

This holistic view of higher education embedded in an organizational structure, which gets transformed to a higher level of sustainability by its members, and which is strongly connected to society and its real challenges, opens up the opportunity for universities to become effective agents of change. (Svanström et al. 2008)

The underlying **holistic transformation process of HEIs** includes a necessary re-definition of learning outcomes of academic educational programs, new methodologies of teaching and learning and the overall redefinition of HE learning environments, giving answers to some of the following questions:

- **Which are the places, tools, methodologies and strategies for the creation of efficient synergies between education, research and innovation for transition towards sustainability, including institutional transformation and outreach to society?**

[5] http://www.ulsf.org/pdf/TD.pdf (accessed June 2015)
[6] http://www.copernicus-alliance.org/images/Downloads/CRE_COPERNICUS_University_Charta.pdf (accessed June 2015)
[7] http://portal.unesco.org/education/en/files/37585/11038209883LuneburgDeclaration.pdf/LuneburgDeclaration.pdf (accessed June 2015)
[8] http://iau-hesd.net/sites/default/files/documents/graz_declaration.pdf (accessed June 2015)
[9] http://www.unesco.or.kr/upload/data_center/2009_ESD_BonnDeclaration_eng.pdf (acc. June 2015)
[10] http://hetreatyrio20.com/wordpress/wp-content/uploads/2013/06/treaty_rio.pdf (acc. June 2015)

- **Where and how can these multi-stakeholder processes be initiated, fostered and managed?**
- **Who are the key players in these transformation processes?**
- **Which are the related desirable learning outcomes, skills and competences, but also values which should be promoted?**

ESD at Schools of Architecture

Within HEIs, building-related disciplines and especially schools of architecture might have an important role and a specific potential in this context. Due to their disciplinary focus on the built environment, enriched through their multi-disciplinary approach to buildings and cities, including technological, economic, social and environmental criteria, their capacity for interaction with university campuses, infrastructures and user communities, as well as their interaction capacity with society and its real-world sustainability problems in cities, might qualify them as effective agents and forerunners in the above described new role of HEIs.

The introduction of new forms of teaching and learning, fostering SD related skills, abilities and competences, and focused on experience-based and participatory learning processes with a holistic, pluridisciplinary view on sustainability, can strengthen their role in this transformation process.

New methodologies and tools in the field of research and innovation, like open innovation processes and living lab ecosystems, together with advanced SD-related teaching and learning activities like participatory learning, co-learning activities or project-based learning within the societal context of university, can generate mutual benefits for both fields of academic activities through the generation of synergies.

Finally ESD related teaching and learning activities at universities might go beyond higher education programs, opening up university campuses and infrastructures to society for life-long learning activities, social outreach of academic knowledge and as starting point for multi-stakeholder processes between HEIs, society, companies and public administrations, fostering an open, multi-disciplinary approach to sustainability and supporting a holistic transformation process of society at all levels.

1.3 Teaching Sustainability in Architecture

The building sector is nowadays the sector with the highest specific amount of energy consumption in the industrialized world and is responsible for almost half of all energy consumption of society today (Herzog 2007). Before the economic crisis, starting in 2008, the Spanish construction sector was responsible for around 24% of the total amount of raw materials required by the Spanish society (Cuchí & Sweatman 2011). This fact claims for a deep change in the design of buildings, materials, systems and technologies, and also its concepts of use, directly related to the life style of society, which should holistically change towards a model of much less environmental impact (Herzog 2007)..

Architecture is from its origins, a discipline which fosters the consideration of and reflection about different kind of resources, like land and territory, materials, energy and water, as well as light and air, with the aim to provide utility, comfort and quality of space for its users.

This context related and resource-efficient approach has been inherent to popular architecture until the beginning of the 20th century, when the availability of cheap and seemingly unlimited sources of energy and the availability of new construction systems and materials as well as building technologies like HVAC (Heating Cooling and Air Conditioning) systems, shifted the focal point of architects to issues of design and representation with the underlying belief of the ability to construct *machines for living* which artificially create and maintain indoor comfort. (Hough 1995)

This decoupling of the buildings from natural resources and the traditional wisdom about the proper exploitation of these resources led to an *international style* architecture, which throughout the 20th century marked the way of conceiving buildings and cities in all western or "developed" societies, and was generally referred to as *modern architecture*.

Since sustainability is now on the agenda, buildings and with them our cities and our society as a whole are expected to be more and more sustainable. Nevertheless, beyond general curricula changes, including additional, sustainability-related learning outcomes, based on skills and competences, there is no consensus about what sustainable architecture is, nor how future architects should be educated in order to contribute to the expected changes in our built environment as well as our society.

The difficult and changing definition of the term sustainability, the missing clear definition of what sustainable architecture is, and a lack of knowledge about how to teach sustainability to architects, has led to a process of experience-based learning regarding the object itself (sustainable architecture) as well as regarding the process of teaching and learning how to develop sustainable projects (being a "sustainable architect"). This was driven by the view of specific educational programs and many individual teaching and learning approaches in HEIs in Europe and beyond.

Since the Bologna Declaration[11] in 1999 which led to the implementation of the corresponding process, the European Higher Education Area (EHEA) has developed a new common framework in order to make HE study programs comparable, compatible and transparent. Within this process, learning outcomes and competences have been defined and developed as main parameters for the description of the different programs, differentiating between first, second and third cycle. (Gonzalez & Wagenaar 2008)

From its start in 2000 the project Tuning Educational Structures in Europe, short *Tuning*[12], has contributed decisively to the creation of a methodology for the design, development and implementation of new study programs under the Bologna Process and later the Lisbon Strategy, contributing to the definition of references on subject area level. The definition of learning outcomes and competences and a change from a staff-centered approach to a student-oriented approach are the essential contributions of *Tuning*.

[11] http://www.magna-charta.org/resources/files/BOLOGNA_DECLARATION.pdf (accessed July 2015)
[12] http://www.unideusto.org/tuningeu/ (accessed July 2015)

Within *Tuning,* the Thematic Network on Architecture ENHSA[13] (European Network of Heads of Schools of Architecture) contributed to the process of structuring the European Higher Architectural Education Area (EHAEA). Extensive consultation work led to a definition of generic and specific competences on professional and specific competences on research in the field of Architecture. (ENHSA 2007)

Nevertheless the restructuring of educational programs within the Bologna Process did not include a specific shift of architectural education towards sustainability, as learning outcomes are described through competences, skills and abilities quite generically. This does not mean that sustainability is not on the agenda of Schools of Architecture, but that the implementation of Sustainable Architectural Education or in a broader sense Education for Sustainability (ES) or Education for Sustainable Development (ESD) remains a challenge to each HEI.

Consequently it is of upmost importance to identify SD competences in higher education in general and in the discipline of architecture in particular, in order to define the right educational methods, pedagogical strategies and teaching and learning tools for their efficient acquisition. This refers to what, how and even where sustainability or SD should be taught or learned at schools of architecture.

Today several frameworks have been proposed in order to approach teaching and learning of sustainable architecture. The EDUCATE[14] (Environmental Design in University Curricula and Architectural Training in Europe) project (2009-2012) is a European Commission funded project with the aim to deconstruct the pedagogical barriers to the integration of sustainability and energy efficiency in university curricula and in the practice of architecture. In its White Paper on Sustainable Architectural Education the authors state:

> *"Sustainability should be integral to architectural design and education. Buildings and urban spaces significantly influence the way of living and thinking of their users. Therefore, it is crucial that academic programs of disciplines of the built environment embrace the key values of sustainable development, which encompass: integration of ecological, economical, and social dimensions; inter- and intra- generational equity; collective responsibility; recognition of scientific uncertainties; and, participation and good governance. As a result, academics and students are confronted with the significant challenge of negotiating a clear path that embraces robust, pluralist, contextually sensitive conceptions of sustainability."* (EDUCATE Project Partners 2012)

Nevertheless, teaching and learning sustainable architecture today is still a rather discipline-focused approach, whereas education for sustainable development (ESD) is based on a holistic, systemic approach beyond disciplinary boundaries. The limits between both are not clearly defined, and specific educational frameworks are missing for one and the other.

Regarding the pedagogical strategies and techniques for ESD in the field of Architecture, a whole new field of educational research opens up in order to define best practices in new forms of learning, new learning environments and innovative student-centered educational strategies, which allow the effective acquisition of SD competences.

[13] http://www.enhsa.net (accessed July 2015)
[14] http://www.educate-sustainability.eu/home (accessed July 2015)

1.4 Living Labs in Architecture

Living Labs are platforms, which involve users in the innovation process by designing, developing and validating new technologies, products or services within real life environments.

The detected gap between Research and Innovation in Europe, the inability of European nations to transform their leadership in research into commercial successes in the marketplace (Almirall 2009) is in the origins of the emerging concept of Living Labs.

Whereas innovation has been formally a task of individuals as entrepreneurs, a collaborative approach to innovation with multiple stakeholders seems to be a valid and useful option in a world of increasing complexity (Almirall 2009). In extremis Open Innovation is defined as an open process where multiple stakeholders collaborate in the process of jointly developing new products or services (Chesbrough 2006). On the other hand user participation in innovation processes has been identified as valuable contribution for market readiness of products and services.

According to these new developments, Living Labs emerged in order to organize and structure user-centered research and participation in innovation, creating a framework for the corresponding activities and interaction among stakeholders.

Living Labs as EU supported strategy for innovation

Within the EU policy framework for information, society and media, focused on "Strengthening innovation and investment in ICT research", and embedded in Co-operation and Policy Support Programs for competitiveness and innovation, Living Labs have been fostered in their quality as interoperable collaboration environments supporting user-driven open innovation processes (European Commission 2009).

With several pilot experiences operating, at the end of 2006 the European Network of Living Labs (ENoLL) was founded under the Finnish Presidency in order to give support and structure further development of Living Labs as methodology and mechanism to strengthen innovation in Europe. This European network has the following objectives (European Commission 2009):

- Offering networking possibilities
- Deriving and sharing benchmarking practices
- Sharing best practices
- Provisioning of services and tools
- Accessing different user communities

Living Labs are based on two main concepts: the involvement of users in early stages of innovation processes and the experimentation in real world environments, structuring user participation (Almirall & Wareham 2008).

According to ENoLL (European Network of Living Labs), "a Living Lab is a real-life test and experimentation environment where users and producers co-create innovations, in a trusted, open ecosystem that enables business and societal innovation."[15]

[15] ENoLL Openlivinglabs website: http://www.slideshare.net/openlivinglabs/introducing-living-labs-and-enoll-41742410 (accessed June 2015)

ENoLL as following identifies 4 main activities of Living Labs:

- Co-Creation: co-design by users and producers
- Exploration: discovering emerging usages, behaviors and market opportunities
- Experimentation: implementing live scenarios within communities of users
- Evaluation: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria.

In their beginnings, Living Labs focused specifically on the area of ICT driven innovations, due to the fact that a huge amount of new ICT products or services showed to be unsuccessful in the market or showed not to be user-friendly, a fact that led to the idea that a user-centric validation within real-life context would be the most efficient way to create need-oriented, user-friendly and consequently successful products and services (European Commission 2009).

Within this domain, supported by the European policy framework of 2010, target areas have been identified and developed through Living Lab projects and actions in the following fields:

- e-Wellbeing
- e-Services in Rural or Developing Areas
- e-Democracy and e-Governance
- ICT for Energy Efficiency

Nowadays diversity of Living Lab initiatives has grown exponentially, with more than 370 accredited members of ENoLL, hundreds of adherent initiatives and many companies, universities, cities and departments, dedicated to support and further develop the Living Lab community, fostering the user-driven open innovation initiatives.[16]

Living Labs in Architecture in HE settings

Higher Education is nowadays a main driver for teaching, research and innovation activities of our society with the aim to contribute to the so-called *progress* of society, lately more and more associated with the term *sustainable development*.

So, with participation and sustainability as two of the main paradigms of our society, and furthermore innovation identified as an important driver to overcome unsustainability of our current economic, environmental and societal frameworks, one important question is how participative innovation processes in the field of sustainability can be fostered in HE institutions.

Based on the given innovation-related and market-oriented definition of Living Labs, this work proposes to research the application of the Living Lab concept in the field of teaching and learning for sustainable development, also called Education for Sustainable Development (ESD) with a specific focus on higher education and the discipline of architecture.

Its assumptions are based on the following considerations:

- **Research and Innovation in Architecture** are inherently related to society, culture, and the local context, so **sustainable development** should be consequently a priority issue for this discipline in higher education. Nevertheless there is no single definition of what sustainable architecture is, how to achieve it and consequently how to generate and teach the corresponding knowledge or foster the corresponding necessary skills and competences.

[16] http://www.openlivinglabs.eu/livinglabs (accessed June 2015)

- Teaching, research and innovation are complementing and overlapping fields of activity in the HE arena with mutually benefits and many synergies to develop and strengthen. EHEA policies pretend to foster specifically competence-based and transdisciplinary education, creating a need for **new teaching and learning methodologies as well as tools and methods** in order to achieve that goal.
- Society expects **solutions to imminent sustainability challenges in the building sector** like energy efficiency, refurbishment of the existing building stock and access to affordable housing for all kind of collectives, but also social innovations to improve resource efficiency of our urban settlements, promote participation and improve the daily life of citizens. This asks for a collaborative effort to provide an efficient outreach of HE research and innovation activities to society.
- Young professionals are expected today to be innovative, to have acquired **knowledge, skills and competences in sustainability** and to be able to generate valuable contributions to societal progress within pluridisciplinary and participative work environments. These competences must be trained within changing HE learning environments e.g. through new active learning methodologies linked to research and innovation, as well as within life-long learning activities for society in general.

Understanding as a priority the **improvement of HE's contribution to SD**, social innovation and general progress of society through teaching, research and innovation, several questions can be raised, based on similar considerations, to which Living Labs intend to give an answer in the general innovation arena:

- **What are efficient physical and legal frameworks, as well as methodologies and tools for participatory teaching and innovation processes in higher education settings?**
- **How can innovation and knowledge generation processes be accelerated in the higher education arena, fostering the outreach of innovation and new knowledge to society in the field of sustainability?**
- **What are the possible tools and strategies for transforming the existing teaching, research and innovation environments of HE institutions into a more transversal, society-embedded, sustainability-driven open ecosystem of teaching, learning and innovation?**

Considering the long tradition of prototype architecture in order to evaluate new forms of living, new technological concepts, building techniques and materials, the idea of architecture labs is not a new one. Chapter 4.2 offers an historical review of 25 important architecture labs of the 20th and beginning 21st century.

Nevertheless, the focus on the user, the evaluation and further development of the applied solutions according to user-centered research and multi-stakeholder, participatory processes in real-life settings are relatively new. This has also to do with the relatively new development of monitoring and sensor technologies, a new focus on the importance of user-behavior (e.g. in the field of energy performance of buildings), and a general new perception of user comfort and user-building interaction, which needs feedback under real conditions of use in order to allow evaluation and improvement of solutions.

Chapter 4.3 describes a selection of 20 Architecture Living Labs[17], which have integrated the user-centered research and innovation approach in real-life settings in one or another way, in order to analyze and compare their characteristics, their applied methodologies, methods and tools, and their contribution to ESD. Around 50% of the projects are driven by research institutes with strong industry participation, the other 50% are based on prototype housing developed by universities in the context of the Solar Decathlon Competitions, a set of international university competitions for the construction of energy self-sufficient solar houses. Some of these prototype buildings have been transformed after the competition into Living Lab projects with teaching, research and innovation activities linked to them.

Chapter 7 describes a specific case study of an Architecture Living Lab within the HE environment of UPC focusing on its concept and specifically its contribution to ESD through an experience-based, participatory and research-related teaching and learning approach.

1.5 Research questions and relevance

Considering the growing importance of education for sustainability in HE in general and in the field of architecture in particular on one hand, and observing emerging new forms of collaborative knowledge generation through Living Labs with a growing number of living lab projects in the field of architecture on the other hand, the following hypothesis has been established:

> ***Living Labs in Architecture can be efficient tools for teaching and learning for SD at universities, with focus on sustainable architecture and life style, beside their important role as infrastructures for applied research and collaborative innovation between university, companies and society.***
>
> ***As knowledge dissemination tools and activities platforms they can contribute to ESD, HEI's SD transitions and the SD outreach of university, fostering holistically the paradigm shift of society towards sustainability.***

This hypothesis led to a series of questions, which guided this research:

- ***What are SD specific competences in higher education in general and in the discipline of architecture in particular?***
- ***What are the existing definitions of Architecture Living Labs and which characteristics are most important for their differentiation and benchmarking?***
- ***What are the specific contributions of Architecture Living Labs to ESD in higher education, HEIs SD transition processes, and societal transition towards SD?***

The first question relates to a **review of SD competences and educational approaches** in higher education, with a special focus on the discipline of architecture.

[17] The denomination of the 20 selected projects as "Living Labs" has been taken, although their living lab characteristics are still to be investigated in this work and some might correspond to the diverse definitions of a Living Lab only to a certain degree. This is in order to avoid a variety of substituting terms like "living-lab like initiatives", "prototypes with living lab characteristics" or similar ones, and is justified through the inexistence of an overall clear definition of the term.

The second question refers to a **phenomenological research regarding the concept of Living Labs**, revising existing theories and definitions, based on an extended literature review. Its answer includes a historical approach to research labs in architecture through a review of major prototype buildings of the 20th and beginning of the 21st century. In addition to this 20 recent Architecture Living Labs are identified and described in order to gain insight into different current project approaches and to identify their main characteristics.

The third question is answered through the proposal of a **framework for Living Labs in Architecture for ESD in HE** and the development of a 3-step **classification tool for Living Labs in Architecture**, based upon identified benchmarking parameters and applied to a selected group of projects.

Finally, a **specific case study** is described and analyzed: Living Lab LOW3 (ETSAV - UPC)
Objects of research are the different stages of development and conversion of the project into an Architecture Living Lab from September 2010 onwards, and the evaluation of its concepts and methodologies, generated outcomes and experiences made in the field of education for sustainable development (ESD).

Relevance
This work is relevant as it contributes to the better understanding of the methodologies, tools and methods applied in Architecture Living Labs with a specific experience and case study - based approach to their contribution in the field of ESD in HE settings, e.g. Schools of Architecture.
It offers a comprehensive approach to benchmarking parameters and a proposal for a classification tool for this type or projects, in order to structure and gain insight into the variety of proposals and make them comparable among each other, identifying best practice and successful concepts as well as weaknesses and threats for this innovative methodology and tool.

1.6 Scope and limitations of this work

This work is focused on researching the concept of Living Labs within the area of architecture, with a specific focus on prototype buildings as educational and research Living Labs at universities.
The work describes a series of Living Lab initiatives related to architecture on an international level, and analyses common characteristics, qualities and outcomes in order to identify benchmarking parameters and to propose a tool for the description and differentiation of initiatives.
Additionally the work evaluates the potential of Architecture Living Labs for ESD in higher education of architects and related disciplines.
Due to the novelty of the Living Lab approach and the specific focus of this work, a limited number of 20 recent Living Lab projects have been identified and researched. Finally a specific field research is conducted on a specific case study of a Living Lab at a School of Architecture, with the author as principal, responsible for the project during the last 5 years. The research is experience-based and experimental. Description, results and evaluation are therefore subjective, as the author formed part of the teaching and learning experiment itself. The related educational research is limited to educational activities organized, executed and evaluated by

the author. Collaborations with similar initiatives on an international level have been established and are described. An overall of 10 educational activities have been documented and analyzed according to their program, methodologies, tools and outcomes, with a specific focus on their contribution to ESD.

1.7 Research methodology outline

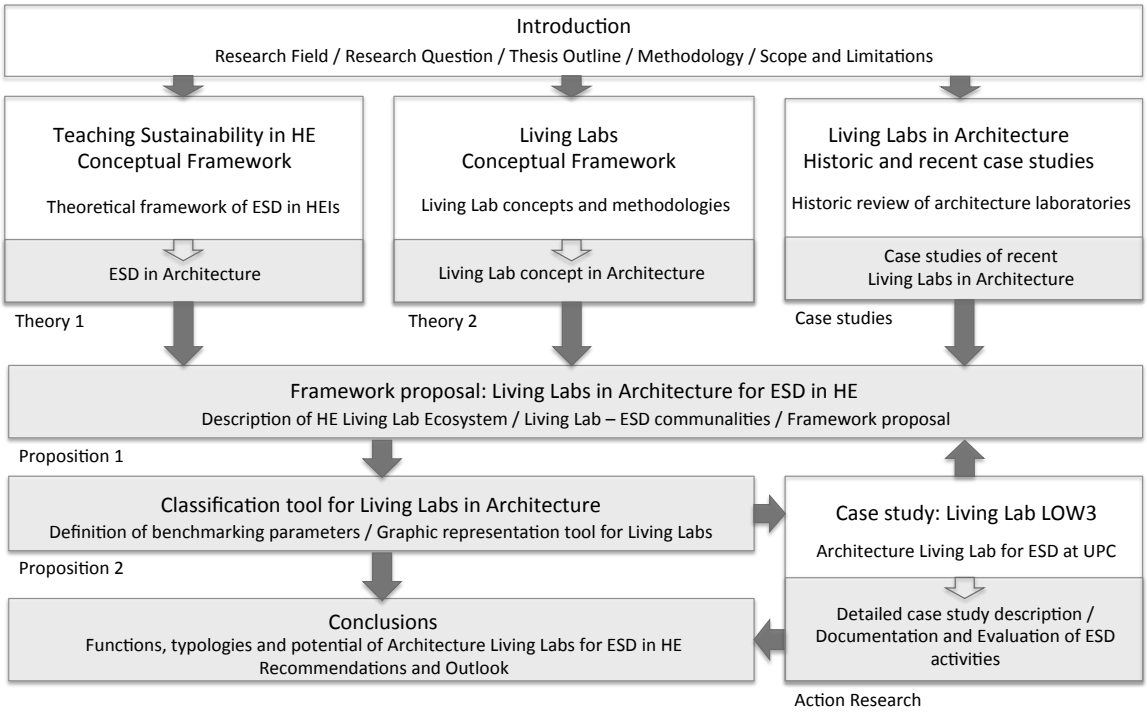


Figure 1.1 Research methodology outline

Theoretical research as well as field research methods get applied in order to give answer to the planed hypothesis. In detail research is divided into the following fields:

- State of the Art analysis of education for sustainable development (ESD) and definition of key fields and key competences for sustainable development of our society with focus on architecture and a more sustainable life style.
- Analysis of the concept of Living Labs and the corresponding theoretical framework, introducing the specific concept of Living Labs in Architecture.
- Description of the historical development and analysis of the current state of the art through a review of 25 historical and 20 recent significant examples of Living Labs in Architecture.
- Proposal of a framework for Architecture Living Labs in HE with focus on ESD.
- Development of a classification tool for Living Labs in architecture in order to analyze and visualize their specific characteristics and allow an approximation and comparison of individual concepts regarding their Living Lab characteristics as well as their ESD related qualities. Benchmarking parameters are defined, applied and contrasted with project leaders through online questionnaires and personal semi-structured interviews.
- Description and analysis of the *Living Lab* LOW3 project as specific case study of an

Architecture Living Lab focused on ESD at UPC. Description of its implementation and operation as innovative teaching and learning tool and supporting infrastructure at the ETSAV campus. This case study can be described as an educational action research project under the leadership of the author, in continuous development since its start in 2010.

- Evaluation of the impact of the project regarding a holistic education for sustainability through mixed method educational research methodology.

The aim is the evaluation of the role which Living Lab concepts can have in architecture, for the necessary shift towards a participative educational model, adapted to the EHEA, which brings together theory and practice, teaching, research and innovation, being at the same time transdisciplinary and international, with a focus on a holistic societal transition towards SD.

1.8 Outline of this thesis

This thesis is organized in 8 chapters as following:

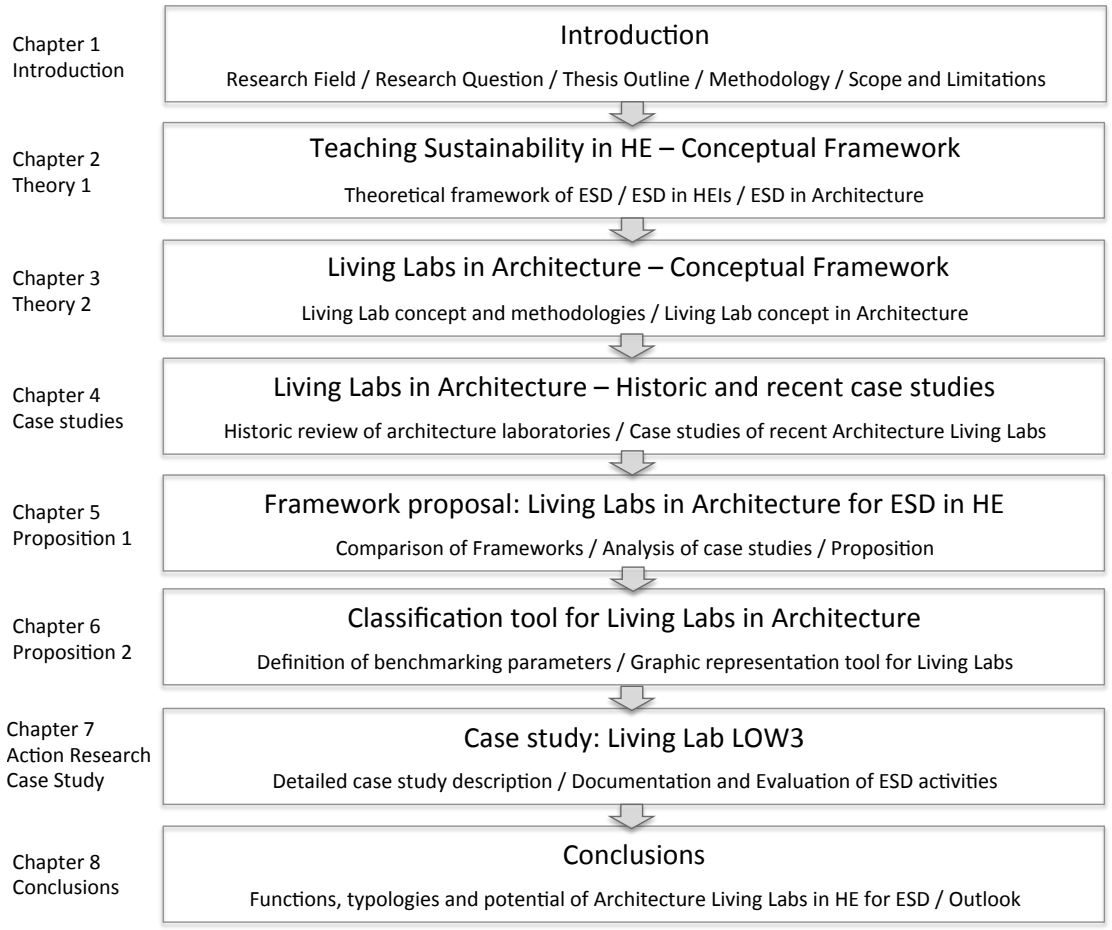


Figure 1.2 Thesis outline

2 TEACHING SUSTAINABILITY IN HIGHER EDUCATION

This chapter introduces the terminology of Sustainable Development in Education (ESD), and its origins and specific goals in the field of architecture as defined today. Based on a broad literature review, the main objectives of ESD and related key competences are discussed and specific areas of knowledge are identified, drawing from the fields of sustainability science and educational science, in order to generate an overview of the current approaches and methodologies of ESD.

2.1 Introduction

Chapter **2.2 introduces the concept of education for sustainable development (ESD)** and gives an overview of frameworks and definitions of ESD in higher education.

Chapter **2.3 focuses on sustainability education and ESD in the discipline of architecture** reviewing relevant literature regarding the general framework and specific definitions of SD competences in the architectural sectors.

Chapter **2.4 analyses three specific concepts related to ESD:** sustainability science, the holistic transformation of HEIs towards SD and transformative learning.

Chapter **2.5 restates the main results of chapter 2 as holistic analysis and and definition of *Teaching Sustainability*** understood as a combination of sustainability education in architecture and ESD.

2.2 Education for Sustainable Development (ESD)

In order to understand how to educate, teach and consequently learn about sustainability, a definition of the term itself is first required. The term sustainability is derived from the Latin word sustinere (tenere, to hold; sus, up) and dictionaries also translate it as endure, maintain or support. In our western society and under an anthropocentric point of view the term is used to describe the continuous availability of resources and services, which allow maintaining human well-being now and in the future.

This basic description of sustainability as the aim of human well-being now and in the future, is also defined by some as a question of the survival of the human species on the planet, and led to the definition of the term Sustainable Development; describing a set of objectives, strategies and values, to which the implementation of ESD is expected to contribute decisively.

2.2.1 Education for Sustainable Development (ESD) - challenges

Sustainable Development

One of the first essential contributions to human understanding of the limited availability of resources for mankind has been the report **"The Limits of Growth"** (Meadows et al. 1972), commissioned by the Club of Rome. Its authors investigated the relationship between mankind and the earth system based on the analysis of five main parameters - world population, industrialization, pollution, food production and resource depletion. A computer simulation of future scenarios under exponential economic growth but with the assumption of limited resources, showed tendencies which predicted the overshoot and collapse of the global systems during the 21st century.

The focus on the relation between development of the human species and its impact on the supporting eco-system of the earth led to the introduction of the term *sustainable development*, although interpretation of the term and definition of the goals of such a development are most widely discussed and no consensus can be expected, due to the complexity and interdependence of the indicators described and parameters introduced. Some environmentalists even see the terms sustainability and development as incompatible, as the later would seem to be the very origin of unsustainability.

One of the most cited but also simplified definitions of sustainable development has been given in the report ***Our common future*** from 1987, also known as the *Brundtland Report,* named after the former Norwegian Prime Minister Gro Harlme Brundtland, director of a UN Commission focused on sustainable development. It defines in its article 27 that "humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations 1987)

The United Nations World Summit 2005 reiterated the importance of a reconciliation of **environmental, economic and societal** aspects, the so-called three main pillars of sustainability. (The United Nations General Assembly 2005)

Nowadays it is generally accepted that sustainability is a **term of difficult definition** and is context related which encompasses a vast amount of diverse perspectives and worldviews. According to its individual worldview, each person experiences and acts differently upon sustainability, driven by certain action logic, values and beliefs. (Lynam 2012)

Wals & Jickling (2002) describe some essential aspects regarding the definition of sustainability and emphasize the **educational potential** due to the **vagueness of its definitions**. Among other definitions, they describe sustainability as a (socially constructed) reality, *as ideology, as a result of negotiations, as contextual as a vision to work towards, as a dynamic and/or evolving concept, as controversial, and the source of conflict* and *catalyst for change.*

This research work cannot go beyond basic concepts and definitions of sustainability and sustainable development, as its main focus is on how to teach sustainability knowledge and

competences in higher education, investigating a holistic, experience-based education through Living Labs in the field of architecture. Nevertheless discipline-based definitions of sustainability and sustainable development in the field of architecture and urbanism, with a special focus on housing and lifestyle will be discussed extensively in later chapters.

Education for Sustainable Development (ESD)

Education in sustainability, often referred also as *education for sustainable development* or ESD, aside from the restraints and discussion about the incompatibility of the two terms, focuses on the knowledge, abilities and competences that should be acquired for attending issues of sustainability in a holistic context.

Education for Sustainable Development (ESD) has been part of educational agendas since it was mentioned internationally in the Agenda 21 document (action plan for sustainable development, result of the UN Conference on Environment and Development in 1992, the *Earth Summit*) as an essential tool for achieving an holistic sustainable development of society.

UNESCO's definition is that "Education for Sustainable Development allows every human being to acquire the knowledge, skills, attitudes and values necessary to shape a sustainable future. "[18]

In a wider context, UNESCO states:

> *"Education for Sustainable Development means including key sustainable development issues into teaching and learning; for example, climate change, disaster risk reduction, biodiversity, poverty reduction, and sustainable consumption. It also requires participatory teaching and learning methods that motivate and empower learners to change their behavior and take action for sustainable development. Education for Sustainable Development consequently promotes competencies like critical thinking, imagining future scenarios and making decisions in a collaborative way."* [19]

In this context the UN Decade of Education for Sustainable Development (2005-2014) intended to give impulse for far-reaching changes in education at all levels, from nursery schools up to universities and in the field of life-long-learning.

In its mission statement, UNESCO puts emphasis that educational programs should "include explicitly the study and comprehension of problems linked to the **social, economic, environmental and cultural sustainability** of our planet, emphasizing interdisciplinary approaches." (UNESCO 2005b)

One important discussion in this context is whether sustainability can be a **quantifiable science** or is more about **values and beliefs**. So, in regards to ESD, one of the main questions is: what are the **fields of knowledge** which have to be fostered or newly introduced and what are efficient **approaches, tools and methodologies**, but also **places and environments** for teaching and learning sustainability.

[18] http://www.unesco.org/new/en/education/themes/leading-the-international-agenda/education-for-sustainable-development (accessed July 2015)
[19] idem

In our rational western societies a **scientific approach** dominates the discussion about sustainability, establishing indicators and measuring parameters, which help to identify a rational framework to understand the complex environmental mechanisms that influence the ecosystems of our planet and the living conditions for mankind in general.

Nevertheless it its generally agreed that an **holistic change of society** will be necessary in order to face a transformation towards a dematerialized economy within the boundaries of the biosphere, and with the consideration of social justice and environmental protection as essential parameters of this new economy. (Martínez-Alier 1998)

A **transition management** is needed based on the establishment of transition arenas and effective learning processes based on learning methodologies which allow a holistic system change towards sustainability (van de Kerkhof & Wieczorek 2005). Transition management must be integrative, happening at multiple scales and needs action from the society as a whole, including all public and private stakeholders. (Kemp et al. 2005)

2.2.2 SD in higher education institutions (HEIs)

Higher education finds itself between the need for disciplinary-bound education focused on the acquisition of specialized knowledge, skills and abilities, and a holistic almost philosophic education, focused on the systemic view and understanding of our world.

Since the 18th century when **disciplinary education** evolved, specific research fields like astronomy, geology, mathematics, physics, chemistry, biology, engineering, architecture, social and political sciences and the arts first developed. **Complexity and system** thinking gained more and more importance in the second part of the 20th century, and sustainability found its reflection first in natural sciences studies like biology and ecology which focused on environmental sustainability and ecosystems. (Komiyama et al. 2011)

Today the **subject of sustainable development** seems to be a requirement in all fields of knowledge across disciplines and at all levels of studies. Nevertheless today higher education is no more than at the start of integrating the knowledge for sustainable development into the official curricula. First, mandatory courses are introduced in technical studies; sustainability offices, institutes and commissions have been founded and are operating at almost all major universities in Europe. Universities have signed Declarations (see chapter 1) compromising themselves to the transition towards SD regarding their **curricula**, but also as **organizations, communities** and as **part of society.** In general, HEIs are seen as **change agents** of society, but need to reorganize and redefine themselves in order to be effective. (Svanström et al. 2008)

Nevertheless, there is an important difference between intentions and implementation, and despite significant advances, many higher education institutions (HEIs) struggle in their **process of transition** towards a holistically integrated approach to sustainability. This has even created certain skepticism regarding the preparation of new declarations or action plans (Filho 2011). HEIs do not differ in this respect from society in general, but could be important **forerunners and key actors** in demonstrating and disseminating how to overcome those generic barriers and difficulties as a community.

HEIs and barriers for achieving sustainability

Reasons for a lacking adoption of sustainability values and practices in society as well as in HEI's can be many. Sibbel (2009) describes 9 specific barriers for achieving sustainability and advocates for the **important role of HEI in overcoming these barriers**.

The barriers are defined as the following:

- *Sustainability as a **challenging concept***, referring to a lack of understanding of the concept due its complexity and the diversity of definitions and models.
- *The limitation of **technological solutions***, referring to the extended belief that *clean* technologies would solely allow achieving sustainability, resulting in less importance being given to social or environmental aspects.
- *The limitations of traditional **regulatory approaches***, referring to the limitation of regulatory approaches regarding the use and design of a product or service, as many of them are rejected as unnecessary cost or conflicting with civil liberties.
- *The limitations of traditional **economic approaches***, referring to price as the dominant determinant of choice for the ordinary consumer, more than a long-term social or environmental impact related to products and services.
- *The limitation of a **consumer based approach***, referring to the over expectation of the contribution of individuals and households as "social decision-making units" to sustainability through consumption choices, based on informed decisions.
- *The lack of **accessibility of information** for decision-making*, referring to information about product and services regarding the related resource consumption, environmental impact or circumstances of production, e.g. regarding labor resources and social impact.
- *The limits to **reliability of information** for decision-making*, referring to remaining uncertainties regarding scientific results, as these are not value free, but filtered for the public, influenced by interest groups, and could therefore be misleading in the decision-making processes of society.
- *The limits to **human information processing capabilities**,* referring to the limitation e.g. of consumers in adopting complex decision making required for sustainability, as individual decision making processes are based on cognitive processes, for example on the perception of quality and reliability of information, as well as being influenced by education, experience, values, attitudes and beliefs.
- *Balancing **individual vs. universal rights***, referring to the need for balancing individual and universal rights in order to assure global sustainability.

Having described these basic barriers for sustainability, Sibbel (2009) **identifies higher education** as a resource for sustainability and an important **agent of societal transformation** towards sustainability, as it trains future professionals, political leaders and educators, who will have a profound impact through their future professional practice and responsibilities in society.

Sustainability research education in transacademic research settings with multiple stakeholder involvement and focused on real-world problems seems to be one way to strengthen this role of HEIs. (Brundiers & Wiek 2011)

Nevertheless many **challenges** have to be overcome by HEIs in order to develop its capacity for contributing to sustainability. According to Sibbel (2009) these are mainly the following three:

- ***Promoting diversity***, referring to the capability of students to find innovative solutions to complex problems through a cooperative and multi-disciplinary approach.
- ***Understanding the concept of sustainability***, referring to the constant analysis and redefinition of the term, using its complexity and ambiguity as inspiration for research and innovation instead of for its simplification and adaptation to existing disciplinary discourses.
- ***Redesigning curricula***, referring to the need for an interdisciplinary approach in curricula, based on concepts of sustainability focused on generating knowledge, values and competences, for analyzing and solving complex problems. These new curricula should draw from social cognitive theory, developing self-efficacy and advocacy skills in students as "motivation, persistence and confidence of success are important attributes in individuals … working towards sustainability" (Sibbel 2009, p. 76). Curricula should furthermore strengthen holistic citizenship education through community involvement, participation and education regarding values. Finally curricula should draw from sustainability science, integrating knowledge of environmental and social science at local and global level, addressing real sustainability problems, developing and testing solutions, including value discussions. (Sibbel 2009)

Transformation of HEIs

Additionally HEI's have to overcome their **organizational and operational limitations** regarding sustainability in order to adopt the role as forerunners of society, create an inspiring, experimental, future-oriented environment for teaching and research within their university campus areas and infrastructures. **Academic communities** can exemplify to society approaches to major sustainability at all levels, from governance, economics, resource consumption, environmental impact and mobility, but also social innovations, models of participation or knowledge generation and management.

These aspects open up important fields of research and innovation regarding HEI's themselves, which cannot be driven through a disciplinary approach and existing organizational structures, nor through following the traditional scientific approach of evidencing the "truth". Transformation depends on a **continuous collective, pluridisciplinary and evolutionary process** towards a higher degree of sustainability.

In order to facilitate these processes key university actors and institutions must work together in order to **overcome structural barriers** at all levels, recognizing the benefits of sustainability education for society and creating the necessary environments for teaching and research (O'Byrne et al. 2014).

Higher education institutions (HEIs) are very important stakeholders in **societies' transition towards sustainability**, but processes of implementation of new paradigms, structures, curricula and operational schemes are complex and depend on the participation and support of the whole institution, generating a **collective process of transformation**.

Education for SD in HEIs

Regarding the definition of learning, and specifically education for SD, it is important to analyze the **concept of teaching and learning** in order to understand the necessary changes in relation to sustainability.

Learning is generally defined as the act of acquiring new, or modifying and reinforcing, existing knowledge, behaviors, skills, values, or preferences and may involve synthesizing different types of information, whereas **education** refers to the processes which facilitate learning.

Wals & Jickling (2002) propose a "*participatory, democratic, pluralistic, and emancipatory approach to education and sustainability"* (p. 226), and relate the integration of sustainability in higher education directly to the **re-thinking of the institutional mission of HEIs**, based on a debate that involves all key stakeholders in universities.

Wals et al. (2002) insist in a continuous **critical review of knowledge and values** as an essential quality of higher education, which corresponds to the need for contextualization and continuous debate regarding the concept of sustainability, as the **knowledge base and associated values of sustainability are unstable** and changing over time (Sibbel 2009).

> *"Higher education has first and foremost something to do with **creating possibilities**, not defining or prescribing the future for our students. These possibilities arise when universities promote the exploration, evaluation, and critique of emerging ideas and the creative contribution to their development. Viewed as such, sustainability is best seen as only one of many stepping stones"* (Wals & Jickling 2002, p. 32).

This means that there is no single approach to teach or learn sustainability but terms like ***diversity*** and ***process*** are used for its description, according to the ambiguous and changing character of sustainability itself.

Collaborative and empathic learning

Jeremy Rifkin in his book the Third Industrial Revolution (Rifkin 2011) describes the **change of educational model in western societies** as an essential part of a third industrial revolution, which would conduct our society towards a new economic era based on renewable energies and a "energy internet". He emphasizes the importance of a new form of **distributed and collaborative learning** as all industrial revolutions have also been based on a communicational revolution. Rifkin describes how changes in energy systems together with changes in communication modified historical human conditions, e.g. how printing techniques allowing communication and organization of society, and together with carbon-driven steam engines as devices for mechanical energy, laid the ground for the first industrial revolution.

He also emphasizes the importance of a **new *biosphere consciousness*** of mankind, and, based on results of neuro-cognitive science and evolutionary biology, he claims that people are biologically prepared for empathy, and instead of irrational, aggressive or narcissist behavior, the nature of mankind would be more affective, social, cooperative and interdependent. This would allow a transition from *Homo sapiens* to *Homo empathicus* allowing the creation of a more coherent society extending empathy beyond limits of nations or race towards the biosphere as a whole (Rifkin 2011).

According to this phenomena of new generations of *digital natives,* which are used to interact and share information in open social networks, **new educational models** would arise, converting the competitive character of education into an experience of **collaborative and empathic learning.** Rifkin states about the transition of the meaning of knowledge that "knowledge as power" would step by step be released by a vision of **knowledge representing the shared responsibility** of all regarding collective well-being.

An important part of this transformation is a new *biospheric consciousness*, which would be currently constructed by mankind, **re-involving itself with nature**, based on the perception of forming integral parts of the universal community of life. (Rifkin 2011)

As the main vision for a new way of education Rifkin describes the following transformation within the educational system:

- A distributed and collaborative education
- Students as empathic beings with shared relations in growing, inclusive communities
- Learning as a social experience, based on participation and linked to real as well as virtual communities
- An extension towards learning on a global scale but also equivalent at local level, with an extension to local community of educational institutions

According to Rifkin (2011) the combination of **formal and non-formal modalities of learning** in more diverse social spaces of society, including new forms like service learning as **transversal elements of the academic curricula** would be essential parts of this transformation.

Considering the rather rigid discipline-based structure of today's universities, the resulting question is which of these new methodologies and tools, as well as collectively driven processes and mechanisms of participation have to be introduced into HEIs in order to make possible these step-by-step transformations towards SD.

2.2.3 ESD within the EHEA framework

The approach to ESD, its frameworks and its definitions have to be seen within the overall higher education structures within Europe.
Since the **Bologna Declaration** in 1999 the **European Higher Education Area (EHEA)**[20] has been developed, being officially launched in 2010, with the aim to unify higher education across Europe according to three strategic goals (EHEA 2012):

- The necessity to improve employability of graduates in the new society of knowledge, with its accelerated obsolescence of knowledge and the need for life-long learning.
- The creation of a common European area of higher education with comparable degrees through the so-called Dublin descriptors for Bachelor and Master programs.
- The adoption of a new paradigm for student centered learning, focused more on the outcome and objectives than on contents.

[20] http://www.ehea.info

A **Framework for Qualifications of the European Higher Education Area (QF-EHEA)** has been developed since then, introducing common degree structures based on a **three-cycle degree system**, and so-called Dublin descriptors have been adopted in 2005 in order to allow "generic statements of typical expectations of achievements and abilities associated with awards that represent the end of each of a Bologna cycle". (Bologna Working Group on Qualifications Frameworks 2005). The central objective of the **Bologna process** is to harmonize the European higher education systems through comparable levels of learning.

Tuning Educational Structures in Europe[21] or *Tuning* is a university driven project, which contributed to the implementation of the **Bologna Process** at the level of higher education institutions and subject areas through a methodology to (re-) design, develop, implement and evaluate study programs for each of the Bologna cycles. (Gonzalez & Wagenaar 2008)

Tuning contributed essentially in the introduction of a new and internationally agreed way of describing study programs through **learning outcomes (LOs)** and **competences** with the aim of making higher education programs comparable and compatible within Europe.

In this context **learning outcomes** (LOs) are defined as "*statements of what a learner is expected to know, understand and be able to demonstrate after completion of a learning experience. … Learning outcomes are expressed in terms of the level of competence to be obtained by the learner".* (Gonzalez & Wagenaar 2008, p. 9)

Competences are defined as "*a dynamic combination of cognitive and meta-cognitive skills, knowledge and understanding, interpersonal, intellectual and practical skills, and ethical values"* (Gonzalez & Wagenaar 2008, p. 9). Fostering competences is the common objective of educational programs. These competences might be of **generic** (common for all disciplines) or **specific** (related to certain field of study) nature.

Competences are usually clustered in three cognitive domains: **knowledge and understanding, skills and abilities**, and **attitudes**. (Segalàs 2009)

Within the QF-EHEA, **generic descriptors for each of the three cycles**[22] have been defined through the following learning outcomes and competences:

	Outcomes
First Cycle - Bachelor (180-240 ECTS)	Qualifications that signify completion of the first cycle are awarded to students who: • have demonstrated knowledge and understanding in a field of study that builds upon their general secondary education, and is typically at a level that, whilst supported by advanced textbooks, includes some aspects that will be informed by knowledge of the forefront of their field of study • can apply their knowledge and understanding in a manner that indicates a professional approach to their work or vocation, and have competences typically demonstrated through devising and sustaining arguments and solving problems within their field of study • have the ability to gather and interpret relevant data (usually within their

[21] http://www.unideusto.org/tuningeu/ (accessed July 2015)
[22] http://www.ehea.info/Uploads/Documents/QF-EHEA-May2005.pdf

	field of study) to inform judgments that include reflection on relevant social, scientific or ethical issues • can communicate information, ideas, problems and solutions to both specialist and non- specialist audiences • have developed those learning skills that are necessary for them to continue to undertake further study with a high degree of autonomy
Second Cycle - Master (60-120 ECTS)	Qualifications that signify completion of the third cycle are awarded to students who: • have demonstrated knowledge and understanding that is founded upon and extends and/or enhances that typically associated with the fist cycle, and that provides a basis or opportunity for originality in developing and/or applying ideas, often within a research context • can apply their knowledge and understanding, and problem solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study • have the ability to integrate knowledge and handle complexity, and formulate judgments with incomplete or limited information, but that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgments • can communicate their conclusions, and the knowledge and rational underpinning these, to specialist and non-specialist audiences clearly and unambiguously • have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous
Third Cycle – PhD or Doctorate	Qualifications that signify completion of the third cycle are awarded to students who: • have demonstrated a systematic understanding of a field of study and mastery of the skills and methods of research associated with that field have demonstrated the ability to conceive, design, implement and adapt a substantial process of research with scholarly integrity • have made a contribution through original research that extends the frontier of knowledge by developing a substantial body of work, some of which merits national or international refereed publication • are capable of critical analysis, evaluation and synthesis of new and complex ideas • can communicate with their peers, the larger scholarly community and with society in general about their areas of expertise • can be expected to be able to promote, within academic and professional contexts, technological, social or cultural advancement in a knowledge-based society.

Table 2.1 Dublin Descriptors for first, second and third cycle of the EHEA qualification framework

Additionally the **European Qualifications Framework for Lifelong Learning (EQF)** was established in 2008 as a common EU reference framework to link countries' qualifications systems and make them more readable and understandable across Europe (European Commission 2008).

EQF is compatibly to the Bologna Declaration and divides learning in 8 levels spanning the full scale of qualifications (lifelong learning approach), with level 6, 7 and 8 referring to the three cycles of higher education (fist cycle or Bachelor, second cycle or Master, third cycle or PhD level) (EDUCATE 2012). **Learning outcomes** are herein divided into **knowledge, skills and competences**.

This new definition of studies based on the related LOs and competences of each course or program needs to be complemented through the introduction of corresponding **competence-based learning methodologies** and **assessment methods** for all levels, a process that is currently ongoing in HEIs in Europe.

Within this new higher education framework, **Education in Sustainability** and **ESD** have to be (re-)defined according to their **corresponding LOs and competences**, raising the questions about what are these specific LOs and competences in the field of sustainability, and which are the **pedagogical strategies** and **learning methods** for fostering them efficiently. In this context some authors even consider necessary **"unlearning" processes** e.g. regarding certain traditionally disciplinary skills, in order to address properly a new learning approach towards sustainability (Vezzoli et al. 2014).

On the other hand, Wals (2009) states that ESD is contributing to **innovation in teaching and learning,** generating and fostering new forms of learning like **social learning, transformative learning** and **context-rich learning** on real community issues. It might be therefore considered that ESD, once defined and initiated within HEIs according to the newly established EHEA framework, starts a **self-generating, evolutionary and open process** of innovation in teaching and learning, due to a **constant re-definition of sustainability challenges** directly related to a constantly changing societal reality. This converts ESD within the existing EHEA framework into a valuable driver for change and evolution of pedagogic strategies and educational methods.

2.2.4 Learning outcomes and competences for SD in HE

Learning outcomes and related competences are the core definition of courses according to the newly introduced EHEA framework for higher education and the approach to competence-based and student-centered learning. Several frameworks for SD education have been developed in recent years in order to define SD specific learning outcomes and competences in HE.

Svanström et al. (2008) compared different declarations (Barcelona Declaration 2004, Tbilisi Declaration 1977) and international SD programs regarding the defined Learning Outcomes and analyzed commonalities in different **sets of learning outcomes for SD in higher education**. The main communalities regarding LOs correspond to:

- **Systemic or holistic thinking**, referring to the ability to cope with complexity and find balance between different dimensions, combining the skills of analytical and synthetic thinking.
- **Integration of different perspectives**, referring to intern- and multi-discipinarity in order to adopt a holistic and balanced perspective, with the capacity to adopt different spatial, temporal, cultural, social or political perspectives.

- **Skills,** referring e.g. to problem solving, critical thinking, creative thinking, self-learning and skills related to communication and teamwork
- **Attitudes and values** appear in the sets of LOs, referring to ethical, economic and aesthetic values, responsibility and solidarity, as well as democratic participatory decision-making.

Based on an review of sustainability programs in several higher education institutions in Europe, Segalàs (2009) describes the main **SD related competences** in the field of engineering disciplines as the followings:

- **Critical thinking** *as the idea of mental processes of discernment, analysis and evaluation in an open-minded point of* view.
- **Systemic thinking** *as the idea that everything interacts with the things around it and that the world therefore consists of complex relationships, which have to be understood as a whole.*
- **Inter- and trans-disciplinarity** *referring to participation of different professionals to solve problems and stakeholder participation in technological processes.*
- **Values and ethics** *as the main force to change attitudes is to act personally and professionally for SD. (Segalàs 2009, p. 21)*

Wiek et al. (2011) developed a reference framework for academic program development regarding the **key competencies in sustainability,** called *integrated sustainability research and problem solving framework*.

In this context they defined competences in sustainability as *a functionally linked complex of knowledge, skills, and attitudes that enable successful task performance and problem solving, with respect to real-world sustainability problems, challenges, and opportunities.* (Wiek et al. 2011, p. 204))

The five key competences related to their framework are:

- **Systems-thinking competence,** referring to *the ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks.*
- **Anticipatory competence**, referring to *the ability to collectively analyze, evaluate, and craft rich ''pictures'' of the future related to sustainability issues and sustainability problem-solving frameworks*
- **Normative competence,** referring to *the ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets*.
- **Strategic competence,** referring to *the ability to collectively design and implement interventions, transitions, and transformative governance strategies toward sustainability.*
- **Interpersonal competence,** referring to *the ability to motivate, enable, and facilitate collaborative and participatory sustainability research and problem solving.*

According to Wiek et al. (2011) the combination of this key competences with basic competences like critical thinking or communication is essential, with **interpersonal competences** as **cross-cutting competence** in sustainability, necessary in almost all other fields in order to collaborate and negotiate with stakeholders.

Wiek et al. (2011) criticize that key competences are not sufficiently linked to specific learning outcomes and that **educational settings** for building sustainability research and problem-solving competence are still at its beginnings. In relation to this they claim **new teaching formats**, which value **collective expertise** in a team, based on complementary individual competencies of its members.

To summarize, there is general agreement on the fact that sustainability requires a **specific set of competences** in order to be addressed properly, and that these specific SD competences need to be complemented with basic competences.

Important SD competences are **critical thinking, systems thinking, multi- or trans-disciplinarity,** with an important role for **values, ethics and attitudes** together with **interpersonal competences. Anticipatory, strategic and normative** competences complement the existing framework of SD competences. Nevertheless competences might shift over time for adaptation to a new set or new definition of sustainability challenges and corresponding new ways of solving them (Wiek et al. 2011).

2.2.5 Pedagogical strategies, methods and tool for ESD in higher education

As "to educate for sustainability is not necessarily educational when sustainability is fixed, pre- and expert determined (i.e. academics) and to be reproduced by novices (i.e. students)" (Wals & Jickling 2002, p. 24). This refers to a necessary change of mental models regarding teaching and learning, understanding the **role of the teacher** also as that of another learner who interacts with others, each one contributing from its own knowledge and standpoint, open for debate about regulatory, ethical and spiritual convictions (Wals & Jickling 2002).

In order to integrate sustainability as constituting paradigm in HEI's, the traditional teaching and learning approach of universities must be redefined **towards problem oriented, experience based learning processes**. Wals & Jickling (2002) outline the necessary transitions as a shift

- *from consumptive learning to discovery learning and creative problem solving;*
- *from teacher-centered to learner-centered arrangements;*
- *from individual learning to collaborative learning;*
- *from theory dominated learning to praxis-oriented learning;*
- *from sheer knowledge accumulation to problematic issue orientation;*
- *from content-oriented learning to self-regulative learning;*
- *from institutional staff-based learning to learning with and from outsiders;*
- *from low level cognitive learning to higher level cognitive learning;*
- *from emphasizing only cognitive objectives to also emphasizing affective and skill-related objectives.*

Warburton & Kevin (2003) refer to another important approach, so-called **deep learning** in sustainability education, fostering the capacity of students to move across disciplines, structure diverse information and to create complex conceptual frameworks.

For deep learning inner motivation of students and their capacity to reflect on their learning is essenctial. Deep learning contrast to surface learning and is often related to problem-based exercises and group processes.

In order to foster the **integration of sustainability in higher education**, Wals & Corcoran (2005) propose 8 principles, which allow introducing corresponding sustainability related methods and approaches in teaching and learning:

Principle	Description	Examples
1. Total immersion	Fostering a direct experience with a real-world phenomenon	Observing and monitoring sustainability impacts Managing a specific site
2. Diversity in learning styles	Being sensitive to the variety of learning styles and preferences that can be found in a single group	Offering a variety of didactic approaches Reflecting on the learning process with the learner
3. Active participation	Developing discourse and ownership by utilizing the learners' knowledge and ideas	Soliciting the learners' own ideas, conceptions and feelings Consulting learners on the content of the learning process
4. The value of valuing	Exposing the learner to alternative ways of knowing and valuing through self-confrontation	Giving learners opportunities to express their own values Creating a safe and open learning environment
5. Balancing the far and the near	Developing empowerment by showing that remote issues have local expressions which one can influence	Relating issues of biodiversity or sustainability to last night's dinner Showing examples of groups of people successfully impacting the local and global environment
6. A case-study approach	Digging for meaning by studying an issue in-depth and looking for transferability to other areas	Assigning different people to explore different angles of a particular theme and bringing the different angles together
7. Social dimensions of learning	Mirroring the learners' ideas, experiences and feelings with those of others through social interaction	Taking time for discussion and exchange Addressing controversy Stimulating flexibility and open-mindedness
8. Learning for action	Making the development of action and action competence an integral part of the learning process	Allowing learners to develop their own course of actions and to follow through with it Studying examples of action-talking elsewhere

Table 2.2 Principles to integrate sustainability in higher education (Wals & Corcoran, 2005)

Based on extensive literature analysis, Segalàs (2009) describes the **pedagogical strategies and techniques** and summarizes their potential contribution to ESD:

Strategy	Description	Contribution to ESD
Lecturing	Lecturing consists of the oral presentation of a subject, even though it can also be a written text.	Regarding ESD, lecturing is a good method to introduce students to sustainability concepts (Azapagic et al., 2005).
PBL	PBL can be described like a set of experiences of learning that involve students in complex projects from the real world through which they develop and apply skills and knowledge.	PBL, especially PBL that is organized as interdisciplinary projects, could contribute to adapt engineering curricula to enhance mutual understanding of science and technology with social sciences (Mulder, 2006).
Case study	Case studies consist of providing a series of cases that represent diverse problematic situations from real life so that they can be studied and analyzed.	Case studies are usually of a qualitative and descriptive nature and can be used to explore specific issues such as different stakeholder perspectives, examples of actual practice, and demonstrations of where progress towards sustainability is, and can be made in the real world (Fenner et al., 2004).
Problem based learning	In problem based learning a small group of students meets, with the support of a tutor, to analyze and to solve a problem designed to attain certain goals of learning.	Problem solving prepares students to be "persons". The characteristics of problem-based learning provide a unique opportunity for students to learn about themselves. As a part of the problem-solving process students must consider their own educational goal, which is likely to require introspection about students' values, ethics and beliefs (Knowlton, 2003; Sterling, 2004b, Huntzinger et al., 2007; McKay and Raffo, 2007).
Backcasting	Backcasting is the creation of a future vision, bearing in mind what it is necessary to achieve in the future and then working towards that goal from this day forward.	Due to its normative and problem-solving character, backcasting approaches are much better suited (in reference to forecasting) to address long-term problems and sustainability solutions (Quist, 2007).
Role play	Role-play can be defined as a learning process in which participants act the roles of other individuals in order to develop particular skills and to meet particular learning objectives.	The role-play is an approach which combines at the same time complexity, the setting in situation, work in groups, autonomy and action of the student is particularly relevant for ESD (Lourdel, 2004b; McLaughlan, 2007; Maier et al., 2007; Dieleman and Huisingh, 2006).

Table 2.3 Contribution to ESD from different pedagogical strategies (Segalàs 2009, p. 53)

These strategies, methods and tools need to be selected and applied thoughtfully according to the educational environment they are getting to be implemented in, the defined objectives and thematic focus, and the group of learners addressed.

2.2.6 International panorama of ESD in higher education

Within the Decade of ESD proclaimed by UNESCO, **20 university chairs** have been established worldwide, specialized in SD with the aim to *"fill the need for both boosting qualifications of sustainable development professionals, and for opening universities to transfer of knowledge and know-how from the field."* (UNESCO 2005b, p. 26).

In its Bonn Declaration of 2009, UNESCO remarks that *"ESD contributes to creating resilient, healthy and sustainable societies through a systemic and integrated approach. It brings new relevance, quality, meaning and purpose to education and training systems. It involves formal, non-formal and informal education contexts, and all sectors of society in a lifelong learning process."* (UNESCO 2009, p. 2)

In the field of higher education, a significant number of international universities have already established individual courses, academic units or whole academic programs, focused on ESD. The EESD conferences bring together since 2002 an important number of international experts for ESD in the field of engineering.

One of the first universities to focus on ESD for engineers has been **TU Delft**, under the lead of Teo Jansen and Karel Mulder, introducing a graduation track "Technology in Sustainable Development" with a generic core course **"Engineering in Sustainable Development"** (deEyto et al. 2013) as early as 1998.

Since 1998, **UPC BarcelonaTech** has been one of the institutions, which has promoted ESD through UNESCO Chairs, the former Cities Program and ultimately through its **University Research Institute for Sustainability Science and Technology (IS.UPC)**[23], focused on ESD teaching and research at third cycle level (Master and PhD level).

On an international level, many initiatives and institutions are linked in order to exchange experience, to collaborate and to network. Examples of these kinds of networks in higher education are the **GUNI Network** – Global University Network for Innovation[24], which focuses lately on Sustainable Development issues, the **Engineering Education for Sustainable Development (EESD) network**, and similar initiatives and organizations.

Some outstanding universities have introduced so-called **sustainability competence centers** in order to implement holistically a culture of sustainability at their institution, e.g. the FSF – Centre for Sustainable Futures[25] (founded 2005) at Plymouth University, which gives support for sustainability teaching and learning across the university, provides curriculum and pedagogic support, coordinates cross-institutional research related to education for sustainable development (ESD) and develops and supports the profile of sustainability across *four 'C's*: Curriculum, Campus, Community, and Culture.

Nevertheless recent studies have shown that **sustainability degree programs** in higher education, despite having increased in number, still fail to integrate natural and social sciences (O'Byrne et al. 2014).

[23] https://is.upc.edu
[24] http://www.guninetwork.org
[25] http://www1.plymouth.ac.uk/sustainability/Pages/teachingandlearning.aspx

Through the evaluation of a total number of 54 internationally identified sustainability degree programs, 27 Master's and 27 Bachelor's Sustainability programs, O'Byrne et al. (2014) detected an important lack of natural science at the master's level and a neglect of the arts and humanities and critical social sciences such as sociology, anthropology, and psychology at both levels.

As sustainability is still a developing, ambiguous and sometimes ill-defined field of knowledge**, more coherence and alignment** between disciplinary and interdisciplinary programs might be necessary in order to integrate ESD holistically in higher education, based on **internationally shared foundations**, **common frameworks** and **successful practices** with documented outcomes and results.

2.3 Approach to ESD in the field of architecture and urbanism

Having outlined the general framework of ESD in higher education, this chapter focuses on the definition of ESD in the field of architecture and urbanism, resuming its main contributions and definitions, which help to approach sustainability in these specific fields.

2.3.1 Sustainability in Architecture and Urbanism – context

In a globalized world, dominated by increasingly **fast processes of change**, including the development of an information and global economy, but also with increasing conflicts and environmental, political and social crisis, **architecture, understood in its cultural dimension,** requires a continuous redefinition of its related values and principles, knowledge, skills and competences as well as its priorities and preferences (ENHSA 2011).

Regarding the education of architects, ENHSA (2011) recognizes a "progressive increase of the gravity of subject areas related to the environment and sustainability" (p. 16) and states that architectural education needs

- *to establish and foster values like transparency, flexibility, adaptability, quality, openness, creativity, innovation, mobility, experimentation, diversity, compatibility, comparability, parametricism and employability;*
- *to become more open and collaborative establishing strong partnerships with other societal actors;*
- *to strengthen the relationship between research, teaching and innovation in a perspective of lifelong learning;*
- *to promote a flexible and creative learning environments;*
- *to consider new, unpredictable, profiles of future architects;*
- *to define competences for architect in a fast-evolving society;*
- *to assure again the generalist character of the degree.*

This list of priorities for the education of future architects reflects the **changes in the field of architecture and urbanism** regarding their cultural dimension and as a supporting system for society, and the need to address increasingly complex challenges in a fast changing and somehow unpredictable world. (Altomonte 2009)

Sustainability in architecture and urbanism refers to multiple challenges regarding **social, economic and environmental sustainability** at local, regional or global scale. Many of them are still not sufficiently defined, and strategies to tackle them are under constant development while disciplinary aspects of these challenges are continuously interrelated to its **multidisciplinary dimension,** and local aspects related to global ones.

Specific areas of interest are for example:

- **Energy in buildings**, including aspects like energy efficiency, new building standards, renewable energy transition, energy storage, European Directives, Energy Democracy, energy poverty or climate change. (Herzog 2007)
- **Materials and resources,** including aspects like environmental impact, sustainable production and consumption systems, lifecycle thinking, biodiversity, waste production, ecological footprint and lifestyle or water conservation. (Martínez-Alier 1998)
- **Sustainable cities,** including aspects like urban metabolism, urban microclimate, urban green, closed cycle economy, quality of life, smart grids, social justice, social innovations, participation, governance, public space, inclusive cities, smart cities, sustainable transport, low carbon society, organic society or transition towns. (Hough 1995; UNESCO 2005b)

The examples show how the disciplinary focus in different areas of interest of architecture and urbanism is **closely linked to generic SD related issues**. Future professionals will need the corresponding competences in order to identify, properly understand and solve complex challenges through a holistic understanding of sustainability at multiple scales.

2.3.2 Definition of ESD for architects – challenges

Education for sustainable architecture and ESD are complementary approaches intended to prepare future professionals in the field of architecture and urbanism.

Regarding the **change in architectural education** and the changing role of schools of architecture ENHSA (2011) states:

> *"Educating architects for an unstable, transformable, changing, adapting, fluid, sometimes hybrid, and more or less unpredictable profile, urges schools of architecture to redefine their educational strategies, to reformulate their curricula and to re-establish their principles and values related to their social role and mission."* (p. 13)

More than half of the world's population today concentrates in cities, and almost half of all energy consumption in industrialized countries is related to buildings, their construction, operation and maintenance (Herzog 2007). **Buildings and cities** are therefore fields of major concern and action regarding environmental, social and economic sustainability (Hough 1995). The concentration of human, economic, technical and political forces in cities requires the right management of these forces in order to attend equally to the social, environmental, economic and cultural dimensions of urban development, predicting and conducting processes of transformation. (UNESCO 2005b)

The management of **public space** regarding democratic principles and **social participation** are essential issues for sustainability in our cities and societies, and in consequence form an important part of education for SD, but are at the same time fields directly related to the disciplines of architecture and urban planning.

UNESCO has established the theme **"Education for Sustainable Urban Development"** as a transversal theme in all sectors and focused on the corresponding issues at the Shanghai World Expo 2010 "Better Cities, Better Life" through the theme "Building Sustainable, Inclusive and Creative Cities".

So who are the stakeholders responsible for a transition towards the sustainable development of buildings and cities? Due to the **complexity** of cities, their infrastructures for transport, energy, water and waste as well as their social and economic metabolism, this challenge needs a **pluridisciplinary and multi-dimensional approach** (Hough 1995). Nevertheless architects and urbanists traditionally play an important, if not leading, role in the design and development of our built environment.

Consequently, if SD is one of the major concerns in our society in general and with it in the fields of architecture and urbanism today, what does this mean for the necessary education of architects regarding sustainable development? What are the **core competences** architects need to acquire in a world of sustainability related challenges and transformations? How can ESD be defined for architects?

The limits between "Education for Sustainable Architecture" and "Education for Sustainable Development" are not clearly defined. **Sustainability is a multidisciplinary and multi-scale concept**, without a clearly defined solution or one single path to follow. Sustainability is about knowledge, skills, abilities and competences, but also about values.

Looking at "Education for Sustainable Architecture" in HEIs, **discourse is often limited** to technical aspects of energy efficiency, the environmental impact of materials and buildings, and a lifecycle approach to buildings and systems. Urban dimensions are often limited to efficient spatial planning, functional definitions and optimizations, and to some extent ecological considerations regarding ecosystem interactions (water, air, urban green).

Sustainable Architectural Education

The white paper on "Sustainable Architectural Education" (EDUCATE Project Partners 2012) as a result of the EDUCATE26 (Environmental Design in University Curricula and Architectural Training in Europe) project from 2009 to 2012 (Intelligent Energy Europe) contributes to an essential definition of the necessary changes in architectural education regarding sustainability through a comprehensive analysis and description of the necessary knowledge, abilities and competences, which need to be fostered for that goal. A consortium of seven European academic partners with the support of regulatory bodies and professionals, has developed *a **framework for the effective integration of sustainable environmental design and energy efficiency in the education and practice of architecture and urban design*** (Altomonte 2012).

[26] https://ec.europa.eu/energy/intelligent/projects/en/projects/educate

A general agenda for sustainable architectural education defines the basic principles for the corresponding transition process (EDUCATE Project Partners 2012):

> *AGENDA FOR SUSTAINABLE ARCHITECTURAL EDUCATION*
>
> *Architectural curricula should foster knowledge, skills and competence in sustainable environmental design, aiming to achieve comfort, delight, well-being and energy efficiency in new and existing buildings, and in urban spaces. This should be promoted within a culturally, economically, and socially viable design process at all stages of the education of building practitioners, by adoption of the following principles:*
>
> *1. Sustainable environmental design should be seen as a priority in the education of building practitioners from the beginning of their studies and through to continuing professional development*
>
> *2. Higher education and professional institutions, educators, students, and practitioners should all be committed to this priority*
>
> *3. Teaching and learning should enthuse and inspire students to rigorously and creatively address design challenges*
>
> *4. Educators should promote a sustainable approach to design through appropriate pedagogical methods, tools and techniques*
>
> *5. The pedagogy should encourage critical awareness, responsibility and reflection of the interdependencies within the design process*
>
> *6. The curriculum should support investigative discourse between different disciplines, parties and professions*
>
> *7. Adequate time, human and financial resources should be devoted to this pedagogical process*
>
> *8. Educators, students and professionals should continually evolve the knowledge base of sustainable environmental design through exemplar research and design practice*
>
> *9. The knowledge base of sustainable environmental design should be disseminated in a manner that is easily accessible to students, academics, practitioners and the general public*
>
> *10. A sustainable architectural education should have the full support of accreditation and regulatory bodies*
>
> (EDUCATE Project Partners 2012)

Emphasis is given in this agenda to the need for early **integration of sustainability** from the beginning, with a holistic commitment by all participants in the process and with the need for **enthusiasm and inspiration**, in order to achieve satisfactory results. The need for appropriate **pedagogical methods** opens up the discussion about educational formats and concepts in higher education and their efficiency and adequacy. The need of **resources** dedicated to a different, generally more complex educational process is stated, and the whole process is clearly defined as **in constant evolution**. Finally **knowledge** must be generated and managed in order to make it easily accessible to students, but also all other stakeholders involved in the process.

It is worth noting that this agenda is titled *agenda for sustainable architectural education* but refers exclusively to **environmental sustainability** related to architecture, excluding a broader view on social sustainability issues, technology use in society or sustainable development in general. These limitations convert this agenda into a **disciplinary approach to sustainability**, which integrates notions of transdisciplinarity, mentioning an *investigative discourse between different disciplines, parties and professions,* but in its core definitions does not integrate a holistic approach to SD.

These different statements lead to the question of **what generic and specific competences** are essential as learning outcomes for education in sustainable architecture and specifically for ESD in the field of architecture.

2.3.3 Specific learning outcomes and competences for SD in architectural education

EDUCATE (2012) proposes the following learning outcomes in terms of knowledge, skills and competences in sustainable environmental design that architectural students should demonstrate at each level of progression towards professional qualification (p. 18):

	Sustainability related program descriptions
First Cycle - Bachelor (180-240 ECTS)	At the first stage of the architectural curriculum, the main principles related to **sustainable environmental design** should be taught as a general introduction to contemporary challenges and as a driver of architectural form, so as to transfer enthusiasm and commitment to sustainability and open the gates of the knowledge and skills needed to creatively explore ideas in design. … This must **include global/local strategies for sustainability**, but also a firm understanding of historical, social and cultural backgrounds.
Second Cycle - Master (60-120 ECTS)	Principles, strategies and solutions of **sustainable environmental design** should be explored more in depth and linked **in an inter-, intra-, trans-, cross-disciplinary and exploratory way to design projects**. Applied coursework should competently address issues of **environmental, social and economic sustainability**, which provide interconnected constraints that need to be creatively addressed in design.

Table 2.4: Sustainability related program descriptions, EDUCATE (2012)

EDUCATE proposes a 3-step model of curriculum, from the exploratory, through a propositional approach to a critical approach regarding sustainability with the following learning outcomes (EDUCATE Project Partners 2012):

1. Stage: Sensitization

Students should exhibit knowledge of:

- *Key values and principles of sustainable environmental design*
- *Precedents and environmental attributes of historic and contemporary buildings and urban spaces*

- *The potential offered by traditional and new materials and technologies to inform design*
- *Benchmarks and environmental standards at national and international level*
- *The relation with other disciplines concerned with the construction sector*
- *The opportunities afforded by the procedures of the building industry and the control of project budgets*

Students should also demonstrate appropriate skills to:

- *Take a critical position in relation to wider issues and objectives of sustainability and its expanding boundaries (including environmental, socio-cultural, political and economic responsibility)*
- *Formulate appropriate environmental design strategies for new or existing buildings and urban spaces informed by climate, site, culture, construction, materiality, building type, and occupancy*
- *Communicate their design explorations and solutions to a specialist and non-specialist audience*

2. Stage: Validation

Students should exhibit knowledge of:

- *The legislative framework and building practices that include awareness of costs and complexity of execution within creative architectural and urban design*

Students should also demonstrate appropriate skills to:

- *Identify, compare and assess environmental impacts and performance of buildings*
- *Make use of on-site observations and measurements, as well as interpretation of performance data and calculated results, to inform design solutions*
- *Recognize the contribution of architecture and urban design in shaping sustainable environments, societies and economies*
- *Develop understanding and ability to interface with other professions within the design process*

And competence to:

- *Promote the propositive nature of design as a generator of new knowledge*
- *Embrace a multi/inter/transdisciplinary approach in tackling issues of sustainable environmental design*

3. Stage: Reflection

Students should exhibit skills to:

- *Take informed and holistic judgments and think critically about the nature of knowledge and how it is produced, validated and expanded*
- *Relate the knowledge acquired to professional development at the various scales of architectural and urban design*
- *Analyze and originally interpret environmental codes and performance targets so as to lead to innovative design and/or research solutions*

And competence to:

- *Commit to cutting-edge scholarly and/or design research, investigating aspects of sustainability individually or as a key member of multi/inter/transdisciplinary international teams*
- *Engage in life-long learning and continue expanding the boundaries of the existing knowledge of sustainable design*

(EDUCATE Project Partners 2012)

These program descriptions show a certain **tendency to integrate general SD discourse**, referring for example to global sustainability strategies or to a multidisciplinary approach, but in its essence are clearly focused on a more disciplinary approach to sustainability.

Regarding considerations about environmental sustainability, which should define contents of architectural curricula, EDUCATE (2012) refers to 4 basic principles (p. 20):

- **Improving the quality of life:** enhancing indoor and outdoor comfort (thermal, visual, acoustic and air quality), health and well-being, whilst carefully controlling the relation between private and public spaces.
- **Decreasing the requests and consumption of energy:** minimizing energy demands during the building construction and operation for cooling, heating, lighting, ventilation and use of appliances, decreasing consumption of energy due to transport (e.g., issues of density and mixed functions), reducing embodied energy of products, and, whenever possible, promoting the utilization of renewable forms of energy.
- **Optimizing the use of materials and other resources:** considering properties and sources of materials, contemplating resource availability, favoring use of renewable materials, promoting recycling and reuse of products, reducing the use of water, facilitating water recycle, restoring water balance, etc.
- **Minimizing waste:** reducing construction and demolition waste by adequate design strategies, design for disassembling, minimize domestic waste, provide infrastructure for recycling and sorting processes, etc.

A broader interpretation of these 4 principals of environmental sustainability could include for example the following aspects relevant to SD:

- **Improving the quality of life:** e.g. can relate to lifestyle, poverty, gender equity, social justice, climate change and mitigation, food security.
- **Decreasing the demand and consumption of energy:** e.g. can relate to production and consumption patterns of society, pathways to a low carbon society, lifestyle changes, transition from centralized fossil to distributed renewable energy systems.
- **Optimizing the use of materials and other resources:** e.g. can relate to resource scarcity, environmental degradation, biodiversity, social innovations.
- **Minimizing waste:** e.g. can relate to circular economy, environmental legislations, production and consumption systems, urban metabolism, and protection of the biosphere.

The 4 principals are **discipline based and project oriented**, as architecture is a discipline based on real projects and design work. Nevertheless, as demonstrated, all 4 concept can be easily applied with a **broader view on sustainability** as understood within education for SD and therefore can serve as a common framework for the **transition from disciplinary to transdisciplinary sustainability education in architecture**, from project related discourse at local scale to a context related discourse on regional and global scale and finally **from sustainable architecture education to ESD.**
This example shows the possibilities to link disciplinary sustainability education in architecture to a holistic education for SD, merging principals and **increasing the scope and complexity** of the disciplinary discourse.

This approach corresponds to the initial statement about within the EDUCATE White Paper on Sustainable Architecture Education (EDUCATE 2012):

> *"Sustainability should be integral to architectural design and education. Buildings and urban spaces significantly influence the way of living and thinking of their users. Therefore, it is crucial that academic programs of disciplines of the built environment embrace the key values of sustainable development, which encompass: integration of ecological, economical, and social dimensions; inter- and intra- generational equity; collective responsibility; recognition of scientific uncertainties; and, participation and good governance. As a result, academics and students are confronted with the significant challenge of negotiating a clear path that embraces robust, pluralist, contextually-sensitive conceptions of sustainability." (p. 6)*

2.3.4 Pedagogical strategies, methods and tool for ESD in architecture education

Traditional course formats like design studios or elective courses might not be the most adequate ways to develop SD related discourse on a broader scale due to **time constraints** and a general high amount of **disciplinary course content**. This again raises the question about **formats, methods,** as well as **tools and places** for establishing a broader SD related discourse in the discipline of architecture.

The EDUCATE white paper gives a series of recommendations regarding methods for teaching and learning (EDUCATE Project Partners 2012):

- The creation of an **integrated cognitive framework** for structuring program contents in theoretical (issues and principles), experiential (applications and case studies) and analytical (tools) domains.
- Seminars promoting **discussions and debate.**
- **Practical, experience-based learning** through site visits, predictions of performance, simulation, verification and direct field measurements.
- Develop **interconnections between theoretical lectures and design studios** e.g. through analysis of case studies, visits to buildings sites, practical investigations, fostering a multi/inter/transdisciplinary approach to design.
- Promote a **research-based, analytic and holistic approach to design,** fostering students' ability of critical thinking, appraisal of data and evaluation of arguments.
- Increase **competence of sustainability at the various stages of the program**, with theoretical knowledge providing support for the design development.
- Promote the **central position of the design studio** throughout the curriculum, as a place for critical and creative thinking, application of knowledge for a holistic vision with the human being and its environment at the center of the design process.
- Foster **student-centered learning** through collaborative, problem-based or experiential learning, ICT and e-learning, team working.

Based on these rather generic recommendations, specific course formats, teaching methods and educational tools should be developed and tested according to the specific context of each HEI, in order to find its individual, efficient way of teaching and learning sustainability.

2.4 Parameters for a change towards SD

In order to change paradigms in HEIs towards disciplinary sustainability education, which are connected to a holistic approach to the ESD of HEIs as communities and important stakeholders in society, the following 3 specific concepts are considered especially relevant.

2.4.1 Sustainability Science

Sustainability science can be defined as a discipline that points the way towards a **sustainable society**, approaching sustainability at global, social and human system level. (Komiyama & Takeuchi 2006)

Since its beginnings, science has been defined as a disciplinary approach, with Francis Bacon establishing in the 17th century the basic principles of inductive reasoning, in order to question and understand natural phenomena. Isaac Newton introduced rules for **scientific reasoning**, laying the foundations of traditional science, based on the establishment of a hypothesis in order to test and validate whether it can be confirmed as true or not through experiments and observation.

Scientific disciplines arose for each field of natural phenomena like geology, physics, and later on social science and economy. Until today, traditional science focuses on experiments, observation and conclusions by induction, which corresponds to the traditional division into **hypothesis, testing and validation** as a basic principle for knowledge generation. (Komiyama et al. 2011)

Nevertheless, this model of science is seen today as responsible for "unintended consequences" which might be happening slowly, but seem to be at least one reason for the degradation processes of global, social and human systems. This leads to the urgent need for **"organizing knowledge for sustainability"** which can be understood as the basis of so-called "sustainability science".

According to Komiyama et al. (2011) sustainability science is based on **three main principles** that differ from the traditional science model:

- Transdisciplinarity
- Integrated analysis
- Generation of knowledge for action

This results in the questions if and how **holistic science departments** for sustainability should be organized today, how they ought to be structured, what the right methodologies and tools would be, and how the results can ensure a "knowledge to action" outcome.

The lack of communication together with increasing specialization and a **missing common language** between disciplines, constitute serious obstacles for an efficient cross-fertilization of ideas and methods among different fields of expertise today.

Nevertheless the **integration of natural, social and engineering sciences** is important in order to understand complex phenomena, which are based on the interaction between human behavior, environmental systems and technology.

According to Kates (2011) sustainability science should bring together **knowledge and action**, and should therefore be regional or place-based, focusing on the **intermediate scales of human-environment systems** in order to foster transition towards sustainability.

Nevertheless, although the term **science** might be inclusive regarding natural science, social science and humanities, other sustainability related areas like engineering, business, design or planning are not clearly included under this denomination, resulting in a certain ambiguity of the term itself. (Wiek et al. 2011)

Table 2.5 shows a comparison between the traditional science and sustainability science approach, in order to understand the profound differences between both approaches.

	Traditional Science	**Sustainability Science**	**Difference**
Aim	To understand everything	To sustain the earth	Separate/total
Object	Anything generally existing in the universe	Specific phenomena	Open/bounded
Result of Research	Knowledge for understanding	Knowledge for action	Analysis/synthesis
Mode of change	Additive	Non-additive	Linear/non-linear
Measure	Unchangeable (any change can be deduced from existence)	Slowly changing	Stable/unstable
Expected practical results	Prosperity and safety of human beings	Sustainability of the Earth	Prosperity/ sustainability

Table 2.5 Traditional science and sustainability science (from Komiyama et al. 2011)

Transdisciplinarity

Transdisciplinarity is one of the key issues of Sustainability Science. Whereas the traditional science approach focuses on one specific field of expertise with a specialization and concentration on one specific research issue, the sustainability science model claims a transdisciplinary view on research issues, understanding the **complexity** and the diversity of research fields related to sustainability as intrinsic for an holistic answer to each problem. Transdisciplinarity requires a robust **integration of diverse disciplinary knowledge** and with it communication and consistency across disciplines. (Komiyama et al. 2011)

According to Popa et al. (2014) transdisciplinarity in sustainability research needs **open-ended, action-oriented transformative approaches** in order to frame and solve problems collectively through experimentation and social learning, supporting **sustainability transition** processes.

HEIs need to foster this approach to sustainability through a general paradigm change regarding its traditional disciplinary science model as well as through the **creation of places, platforms or programs** for transdisciplinary interchange, collaboration and experimentation.

Integrated analysis
Disciplinary highly specialized knowledge is increasingly inconsistent in its contribution to solve complex global problems of system degradation. An integrated analysis refers to the holistic view, which sustainability science claims to adopt in its definition. Komiyama et al. (2011) refers to the need for a robust integration of knowledge at different levels referring to **natural, engineering and social science** knowledge which merges in the future into *integrated knowledge on an abstract level*.

Knowledge for action
The generation of knowledge for action is the opposite of the generation of knowledge for the purpose of itself, mainly linked to basic research of all kind of fields. The generation of knowledge for action, implicit in the definition and objectives of sustainability science focuses on the **applicability of generated knowledge** for the instance of change.

Interconnection between basic research, applied research, development and innovation
As a consequence of the 3 main parameters which define the model of sustainability science, the focus of this scientific approach fosters a combination of **basic and applied research** as well as its connection to **development and innovation**.

2.4.2 Transformative learning

Another widely discussed form of learning within the approach of sustainability science can be understood as the so-called **transformative learning processes**. Transformative learning is based on three main pillars for a holistic transformation of perspective through profound changes: **psychological transformation** through changes in understanding of the self, **convictional transformation** through a revision of one's belief systems, and a **behavioral transformation** resulting in changes in one's lifestyle. (Boehnert 2012)

In this sense, transformational learning is defined as learning that induces more far-reaching change in the learner than other kinds of learning, and can even provoke a **paradigm shift in** the learner, helping him to put new ideas into practice (Boehnert 2012).

A transformative learning experience depends on many factors like an open, community-creating learning environment, which allows sharing experiences and values, based on trust and team spirit.

According to Mezirow, one of the main theorists in the field, transformative learning is based on **critical reflection about experiences**, and is mainly based on a rational process. Furthermore, he believes that what he calls "disorienting dilemmas", related to major moments of crisis and change, favorite transformational processes. Mezirow (cited in Boehnert 2012) describes the objective and outcome of transformative learning in the following way:

> *"A defining condition of being human is that we have to understand the meaning of our experience. For some, any uncritically assimilated explanation by an authority will suffice. But in contemporary societies we must learn to make our own interpretations rather than act on the purposes, beliefs, judgments, and feelings of others. Facilitating such understandings is the cardinal goal of adult education. Transformative learning develops autonomous thinking."*

In the specific field of **education for sustainability**, co-creation of knowledge and a collective, experience based learning process might be one form of transformative learning, based on dialogue, a critical thinking process and common experience, which lead to the creation of new knowledge and the step by step assumption of **new attitudes and paradigms**.

Boehnert (2012) develops an adaptation of Mezirow's ten phases of transformative learning to ten phases for sustainable design education:

	Transformative Learning phases (Mezirow 2009)	Phases of Sustainable Design Education (Boehnert 2012)
1	A disorienting dilemma	Confrontation with information regarding the environmental crisis
2	Self-examination	Self-examination of personal attitudes in regards to environmental crises
3	A critical assessment of assumptions	A critical assessment of assumptions and basic premises
4	Recognition of a connection between one's discontent and the process of transformation	Recognition of discontent and possibilities for transformation
5	Exploration of options for new roles, relationships and actions	Exploration of sustainability in a social learning context
6	Planning a course of action	Plan a learning process for sustainable education and ecological literacy
7	Acquiring knowledge and skills for implementing one's plans	Acquire new knowledge and skills needed in sustainable industries
8	Provisional trying out of new roles	Develop sustainable methods of working and living
9	Building competence and self-confidence in new roles and relationships	Build confidence to actively embed ecological literacy into one's life
10	A reintegration into one's life on the basis of conditions dictated by one's new perspective	Integration of ecological literacy to life in all spheres (personal, professional and political)

Table 2.6 Ten phases for sustainable design education (Boehnert 2012)

Regarding HE and the discipline of Architecture, the fundamental changes in the **role and professional profile of architects** in society require a **place for individual and collective reflection** about these changes, from a short-term, profession-oriented perspective about job opportunities, new fields of activities for architects and corresponding specialization, to a long-term, life-oriented perspective about values, convictions, and motivations for the development of an identity as a citizen as well as a professional, contributing to the overall development of society.

> *"Transformation is achieved when you go beyond factual and instrumental learning and are changed by what you learn. In order to achieve transformational learning you must critically reflect on your knowledge and experiences, continuously question your assumptions, beliefs and values, and act accordingly in your personal life, professional life and community life."* (Svanström et al. 2008)

Another aspect of transformative learning in higher education in the field of architecture refers to the need for transformation not only of higher education but also of "higher educators". The introduction of new forms of learning such as transformative learning experiences needs highly sensitive and trained **educators able to conduct such processes**.

2.4.3 Transition management in HEIs towards SD

Higher Education Institutions (HEIs) play an important role in sustainable development (SD), educating whole generations of new professionals, which will decisively shape the future of society through their skills, competences and values regarding sustainability. HEIs are increasingly incorporating sustainability values and practices in their core activities of **teaching, research and innovation**, as well as in their **operational structures** (governance, infrastructures, operation, academic community) and in their **outreach to society regarding SD**.

In all of these three main areas of operation and influence, HEIs should attend the multiple objectives of environmental, social and economic sustainability.

New participatory mechanisms, protocols or strategies and tools **for transition management in HE environments** are necessary, fostering envisioning and collective action processes for the design and development of new pathways for HEIs as a whole, and for their specific disciplinary environments:

> *"Transition management aspires to be inclusive and calls for setting medium- and long-term goals, for aligning short- and long-term policies, and for conducting strategic experimentation to supplement the use of traditional policies (e.g., regulation, taxes). It aims to achieve systemic change through small steps in strategically chosen directions. The "management" that is involved works through self-organization and uses visions and feedback cycles to convey the lessons of new experiences and endogenous institutionalization."* (Kemp & Martens 2007)

Institutionalized units in HEIs, committed to the introduction of ESD in HE might be politically stronger in the implementation process of transition policies towards ESD, but might not have the same **open, participatory bottom-up approach**, which can be facilitated by distributed participatory projects such as, for example, **Living Labs for ESD** at the site of faculties. A strong connection and collaboration between both approaches, including the activation of intermediate structures of faculties (departments, research groups), creating a **transversal platform** for visioning and action, might be the most effective way to foster ESD in HEIs.

2.5 Summary and conclusions

Sustainable development requires the reconciliation of **environmental, economic and societal** aspects, the so-called three main pillars of sustainability. (UN 2005)

It can be stated that SD in higher education institutions is still at its beginnings, as it requires a **holistic transformation process of HEI's towards SD** regarding **curricula development**, but also regarding **organizations, communities** and as **part of society.**

ESD focuses on a change of the traditional disciplinary paradigm towards the introduction of multi and transdisciplinary approaches to research and teaching regarding **social, economic, environmental and cultural sustainability.**

ESD in HEIs has an **important role for society** as a whole, as it trains future generations of professionals and leaders generating the necessary knowledge, skills and competences for approaching sustainable challenges. (Svanström et al. 2008)

Additionally HEI has the role of an **agent for societal transformation**, demonstrating how to **overcome existing barriers** to sustainability. By constantly **searching for solutions** from a collaborative, creative and open point of view based on diversity, a continuous search for further clarity and definition of the constant changing concept of sustainability, will avoid its disciplinary simplification, and develop **curricula based on sustainability concepts**, including interdisciplinary, competence based, value and citizenship education as well as sustainability science principals (Sibbel 2009).

In order to implement SD holistically, HEIs need to start a transformation process, which includes not only **curricula but also organizational and operational transformations**. **Institutional missions of HEIs** must be redefined within a continuous **critical review of knowledge and values (**Wals et al. 2002) as our understanding of sustainability changes over time.

SD is related to a **distributed, collaborative and empathic learning** approach with a new ***biosphere consciousness,*** understanding learning as a social experience with formal and non-formal modalities (Rifkin 2011).

Within the **Framework for Qualifications of the European Higher Education Area (QF-EHEA)** study programs are defined through **Learning outcomes (LOs)** and **competences.** Competences are usually clustered in three cognitive domains: **knowledge and understanding, skills and abilities**, and **attitudes**. (Segalàs 2009)

Main ESD competences are identified as **critical thinking, systems thinking** and **multi- or transdisciplinarity,** with an important role for **values, ethics and attitudes** together with **interpersonal competences. Anticipatory, strategic** and **normative competences** complement the existing framework of SD competences.

ESD is contributing to **innovation in teaching and learning,** generating and fostering new forms of learning like **social learning, transformative learning** and **context-rich learning** on real community issues (Wals 2009).

In the context of ESD established **pedagogical strategies**, **teaching methods** and **educational tools** have to be questioned and new approaches have to be integrated regarding **student-**

centered, collaborative and praxis-oriented learning and **creative problem-solving**, applying principals like **active participation, case-study approach, learning for action, diversity in learning styles** or **total immersion**, and applying strategies and methods like **project-based learning, problem based learning, backcasting** or **role play**.

Sustainability degree programs, sustainability competence centers, international networks and **conferences** are internationally increasing in number over the last few years. Nevertheless many degree programs show a lack of the integration of natural and social science (O'Byrne et al. 2014), and more **coherence and alignment** between disciplinary and interdisciplinary programs might be necessary, in order to integrate ESD holistically into higher education.

Sustainability in architecture and urbanism refers to multiple challenges regarding **social, economic and environmental sustainability** at a local, regional and global scale.

Sustainable architectural education attempts to integrate robust, diverse, context-sensitive concepts of sustainability into architectural education, fostering corresponding specific competences for the integration of **environmental, social and economic sustainability** issues.

Transition from disciplinary to transdiscipinary, holistic sustainability education in architecture is possible through widening the adopted perspective from project related discourse at local scale to context related discourse on regional and global scales, shifting from **sustainable architecture education** to **education for sustainable development (ESD).**

Pedagogical strategies, methods and tools for ESD in architectural education should be based on an integrated cognitive framework, discussions and debates, practical and experience-based learning, the interconnection between theoretical lectures and design studios, a research-based, analytic and holistic approach to design and student-centered learning, including collaborative, problem-based or experiential learning. (EDUCATE Project Partners 2012)

Sustainability science, based on the principals of transdisciplinarity, integrated analysis and the generation of knowledge for action, focuses on the **integration of natural, social and engineering sciences** in order to understand complex phenomena, resulting from interaction between human behavior, environmental systems and technology. The **action-oriented, transformative research** approach of sustainability science, generating **applicable knowledge** for the purpose of change reflects a combination of **basic and applied research** as well as its connection to **development and innovation**.

Transformative learning is based on **psychological transformation** through changes in understanding of the self, **convictional transformation** through a revision of one's belief systems, and a **behavioral transformation** resulting in changes in one's lifestyle. (Clark, 1991)

In the specific field of **education for sustainability** or **ESD in architectural education**, co-creation of knowledge within a collective, experience based, problem-based or project based learning process might allow the generation of a transformative learning experience.

HEIs are increasingly incorporating sustainability values and practices in their core activities of **teaching, research and innovation**, as well as their **operational structures** (governance, infrastructures, operation, academic community) and **outreach to society regarding SD**.

New strategies, tools and methods are necessary for an overall **transition management of HEIs towards SD**, allowing ESD to be integrated into a comprehensive SD environment of HEIs.

In the following chapters the concept of **Living Labs as research and innovation approach** will be introduced analyzing their characteristics and detecting possible **similarities and synergies with the concept of ESD**. The objective is to point out to what degree Living Labs, specifically in the discipline of Architecture, can contribute efficiently to discipline-based sustainability education as well as to holistic Education for Sustainable Development (ESD) in higher education, and with it, to the **holistic transformation process of HEI's** towards sustainable development.

3 LIVING LABS IN ARCHITECTURE – CONCEPTUAL FRAMEWORK

This chapter introduces the term Living Lab, the origin and definition of the concept, its conceptual framework and the current state of the art of this relatively new approach to innovation through participation and co-creation. Furthermore it offers a specific interpretation of the concept for the field of Architecture.

3.1 Introduction

Living Labs are based on an innovation concept developed at the end 1990's. In order to understand their underlying principals, organizational structure and specific qualities, **chapter 3.2 offers an introduction into the existing conceptual framework of Living Labs and a general review of the current state of the art**, with a specific analysis of the on-going research into Living Labs and their evolving methodologies, conceptual frameworks, strategies and tools through an extensive literature review.

One specific approach of Living Labs relates to Architecture**,** using prototype buildings, experimental home environments or real buildings as environments for their activities. **Chapter 3.3 introduces the specific Living Lab approach within Architecture**, the origins of this specific type of Living Labs, an approximation of their definition, objectives, formats, applied methodologies, methods, tools and outcomes.

As many Architecture Living Labs are strongly related to sustainability in fields like energy efficiency, environmental impact, innovative housing concepts and lifestyle, and many recent projects have their origin in Higher Education Institutions or related research entities, **Chapter 3.4** analyses the role of **Architecture Living Labs in Education for Sustainable Development (ESD)** in higher education. Specific characteristics of the Living Lab approach are compared to the ESD approach regarding **ESD related competences, pedagogical strategies and applied methods** as well as regarding the typical settings, organizational aspects and outreach of each activity.

3.2 Living Labs – conceptual framework

Living Labs (Living Laboratories) are platforms, which **"involve users in the innovation process by designing, developing and validating new technologies, products and services within real life environments"** (Almirall, 2008, p.22). According to the growing number of living lab initiatives, networking structures have been established, which in recent years, have allowed the reinforcement of the theoretical framework of Living Labs as well as a comparison of the diverse Living Lab methodologies, tools and approaches applied. The ENoLL – European Network of Living Labs[27] actually comprises more than 370 accredited Living Lab activities worldwide with a strong growth during the last years.

This chapter introduces the origins of Living Labs and summarizes their main characteristics, giving an overview of the principal parameters, which allows them to be differentiated.

In order to structure this theoretical approach to the conceptual framework of Living Labs, this chapter highlights the **origins of the term and current definitions, relationship of the organizational structures of Living Labs, the focus on the role of the user, the discussion of the related open innovation approach, and reflections on the experimental approach in real-life environments**.

Additional determining aspects will be discussed such as the identification of their main drivers, the role of ICT technologies and social innovation versus technological innovation in Living Lab environments.

3.2.1 *Introduction to the concept of Living Labs*

Origins of the term

William J. Mitchell from MediaLab and School of Architecture and city planning at MIT first used the term *Living Lab* at the end of the 1990's, looking for new **mechanisms to involve inhabitants** in urban planning and design (Magdala & Pedruzzi 2013).

The first Living Labs focused on the area of **smart or future homes**, researching the usage of emerging technologies in the real-life environment of a home, with people testing the home for days or even weeks (Eriksson et al., 2005).

At the same time as Mitchell, Abowd and his colleagues at Georgia Institute of Technology used the term ***Living Laboratory*** to refer to real-world contexts in which users could get in touch and test state-of-the art technology (Følstad, 2008).

Over the last 15 years Living Labs have evolved within the European R+D+I context as organizations which structure and provide governance to user involvement within **"innovation arenas"** where different stakeholders can experiment and innovate in real-life environments (European Commission 2009).

[27] http://www.openlivinglabs.eu (accessed August 2015)

The purpose of Living Labs

The need for accelerated innovation as a motor for economic growth and competiveness in the globalized market, has been identified as key for a European society on its way to higher productivity. Boosting innovation through the participation of user/citizen/consumers within innovation processes, and fostering the **role of consumers as producers**, allows benefiting from additional ideas, knowledge and experiences.

The European Commission (2009) describes the role of Living Labs as the following:

> *"Living Labs have in general an important role in filling gaps. They bridge the different gaps between technology and development on the one hand, and market entry and fulfillment on the other. As flexible ecosystems, Living Labs can provide a demand- driven 'concurrent innovation' approach by iteratively engaging all the key actors across the phases, and putting the user in the driver's seat. Living Labs often start their bridging in the applied research phase. Taking the step from technology prototypes for innovative and visionary users to evolving products for pragmatic and mainstream users, also called crossing the "pre-commercial gap" or "chasm", is the major acting field for Living Labs as iterative user involvement adds significant value to the rapid prototyping and service/product development phases."* (European Commission 2009)

Emphasis is given in this definition to the **role of *mainstream users*** (different to the concept of so-called *lead users* (von Hippel, 2005, p.4)) who contribute to development in the advanced prototyping phase, in order to reach a market-ready level of a product or service. The denomination of **Living Labs as *flexible ecosystems*** underlines the open character of Living Lab initiatives regarding the integration of multiple stakeholder with different backgrounds, the diversity of drivers, the specific role of users, and the collaborative character of the innovation process itself.

Definitions of Living Labs

Based on an extensive literature review, the following 10 different definitions are cited textually in order to identify the main common characteristics of Living Labs, among an increasing variety of interpretations.

> *"A Living Lab is an **Open Innovation ecosystem** frequently operating in the context of competitiveness clusters and public development agencies within social innovation environments engaging local authorities in territories such as cities, agglomerations, regions."* (Pallot et al. 2010, chap. 1)

> *"A Living Lab is not just a network of infrastructure and services, but much more a **network of real people with rich experiences**; it is a new way to deal with community-driven innovation. The Living Lab approach represents a **research methodology** for sensing, prototyping, validating and refining complex solutions in multiple and evolving real- life contexts."* (Mulder et al. 2008, p. 2)

> *"Living Labs are **open innovation environments** in real-life settings, in which user-driven innovation is fully integrated within the co-creation process of new services, products, and societal infrastructures."* (Mulder & Stappers 2009, chap.1)

> *"Living Lab can be interpreted and used as a **human-centric research and development approach** in which ICT innovations are co-created, tested, and evaluated in open, collaborative, multi-contextual real-world settings."* (Ståhlbröst 2008, p. 4)

> *"Living Labs are commonly **Public Private Partnerships (PPP)** committed to communities that contribute to their funding. Also they provide a wide range of services and play diverse roles in the quest for articulating user involvement, from support to entrepreneurial lead users to needs-finding or user experience services. (…) Their goal is no other than the creation of "innovation arenas" where multiple actors experiment in an open, real life environment."* (Almirall & Wareham 2008, p. 22)

> *"**Living Labs organize users in needs finding exercises** contributing to ideation, support them in acting as entrepreneurs, orchestrate the innovation process, organize user contribution in incremental innovation through localization exercises or promote societal involvement for a certain platform, product or service. Therefore, playing a more **encompassing and systemic role** in the innovation process."* (Almirall & Wareham 2008, p. 24)

> *"[A Living Lab] is a **systemic innovation approach** in which all stakeholders in a product, service or application participate directly in the development process. It refers to a **research and development (R&D) methodology** in which innovations are created and validated collaboratively in multi-contextual, empirical real-world environments"* (Feurstein & Hesmer 2008, chap. 1.1.)

> *"[The Living Lab concept] is used to describe an **experimental platform** where the user is studied in his or her everyday habitat. It can also be seen as an **eco-system** where users are subjected to a combination of research methodologies while they test new technologies that are still in development."* (Schuurman & De Marez 2009, chap. 5)

> *"Living labs **provide physical regions or virtual realities** in which a number of actors, including users, apply open-innovation principles to co-create and test innovation in real-life contexts."*(Nyström et al. 2012, p. 10)

> *"A Living Lab is a **user-centric innovation milieu** built on every-day practice and research, with an approach that facilitates user influence in open and distributed innovation processes engaging all relevant partners in real-life contexts, aiming to create sustainable values."* (Bergvall-Kåreborn & Box 2009, chap. 2)

These definitions reflect the diversity of concepts, which are related to the term Living Lab, describing them **in three basic categories**:

- **Environments, ecosystems, milieus or networks**, addressing the complexity of the concept as organizational structure for innovation processes.
- **Research methodology**, referring to an application of a specific research approach.

- **Service provider**, offering an **infrastructure or place (physical or virtual)** to carry out user-centered research and innovation activities.

Main **objectives and corresponding activities** deriving from the diversity of definitions are:

- *"Sensing, prototyping, validating and refining complex solutions"* (Mulder et al. 2008, p.2)
- *"Co-creation … of new services, products, and societal infrastructures"* (Mulder & Stappers 2009, chap. 1)
- *"ICT innovations are co-created, tested, and evaluated …"* (Ståhlbröst 2008, p. 4)
- *"Creation of "innovation arenas" where multiple actors could experiment"* (Almirall & Wareham 2008, p. 22)
- *"Innovations are created and validated"* (Feurstein & Hesmer 2008, chap. 1.1.)
- *"Organize user contribution in incremental innovation … or promote societal involvement for a certain platform, product or service."* (Almirall & Wareham 2008, p.24)
- *"The user is studied in his or her everyday habitat."* (Schuurman & De Marez 2009, chap.5)
- *"[To] provide physical regions or virtual realities" and "to co-create and test innovation in real-life contexts"* (Nyström et al. 2012, p. 10)
- *"… facilitates user influence … engaging all relevant partners"* (Bergvall-Kåreborn & Box 2009, chap. 2)

From the above definitions of Living Labs the following variety of descriptions of **settings of Living Labs are derived:**

- *"Social innovation environments"* (Pallot et al. 2010, chap. 1)
- *"Multiple and evolving real-life contexts, multi-contextual real-world settings" (Mulder et al. 2008, p. 2),*
- *"Open, real-life environments"* (Almirall & Wareham 2008, p. 22)
- *"Open, collaborative, multi-contextual real-world settings"* (Ståhlbröst 2008, p. 4)
- *"Multi-contextual, empirical real-world environments"* (Feurstein & Hesmer 2008, chap.1.1.)
- *"Everyday habitat"* (Schuurman & De Marez 2009, chap. 5)
- *"Physical regions or virtual realities"* (Nyström et al. 2012, p. 10)
- *"Innovation milieu … in real-life contexts"* (Bergvall-Kåreborn & Box 2009, chap. 2)

Qualities of environment and process are described as *multiple and evolving, open, collaborative, multi contextual, real life, real-world, empirical real-world, experimental* and *physical or virtual.*

Stakeholders of a Living Lab are mentioned as *competitiveness clusters***,** *public development agencies, social innovation environments, local authorities, cities, agglomerations, regions, community, people, lead users, users,* and in general *multiple actors*, which, according to the literature review include especially companies, research institutes, universities and other public or private institutions.

Sectors of application

Living Labs have been developed in recent years in diverse fields of application. **ICT applications** played an important role right from the start and still have a predominant position within Living Lab initiatives. Sectors like **e-Health, Ambient Assisted Living, e-Inclusion, e-Transportation, e-Government, Smart City, ICT for Energy, and ICT for Environment** are areas of application of ICT solutions in diverse fields of society. (Pallot et al. 2010)

Botnia Living Lab[28] in Sweden, with Lulea University as main stakeholder, is one of the major ICT related Living Labs in this field with more than 6000 co-creative pilot users and diverse application areas like mobile marketing, traffic information, energy saving, sports and culture, e-democracy and security.

Systems, materials and technologies related to the **built environment** are another important area of application, as testing and validation with users under real-life conditions e.g. of innovations for home or work environments, allows direct feedback regarding user acceptance, usability and the adaptation to user needs, helping to guarantee market viability and success.

The **Fraunhofer InHaus Center** in Duisburg, Germany, (see also chapter 4.3) is a research institute, which follows this approach through its application labs, which allow an integrated chain of innovation from research through to application and market, by developing, building, testing and evaluating 1:1 prototype solutions together with stakeholders and with the participation of users under real-life conditions.

Pallot et al. (2010) describe the generic and broad applicability of the Living Lab approach as following:

> *"A Living Lab can operate with a research and innovation platform for providing access to science and innovation services allowing enterprises and users/citizens either as entrepreneurs or communities. The main objectives consist to explore new ideas and concepts, experiment new artifacts and evaluate breakthrough scenario that could be turned into successful innovations."* (Chap. 1)

In this sense the **applicability of the Living Lab approach** is open to any discipline or field of knowledge, which benefits from open, multi-stakeholder approaches to innovation and user feedback and co-creation in a real-life environment during development.
The application of Living Lab methodologies seem to be specifically efficient in cases, where multiple stakeholders have conflicting interests and where a specific technology will fit to a precise context, with user acceptance playing a major role. (Almirall et al. 2012)
The concept of Living Labs is in line with a whole series of recent **societal trends**, like participatory processes, communities of users, social networks, and **technological streams** like the Internet of Things, Cloud Computing, Big Data and User Content Creation. (Pallot et al. 2010)
Therefore, beside the above-mentioned fields of **technological innovation**, the field of **social innovation** might, in the near future, benefit increasingly from the conceptual approach of Living Labs.

[28] http://www.ltu.se/centres/cdt/Vart-erbjudande/Experimentmiljoer/Botnia-Living-Lab-1.111199?l=en

Main characteristics of Living Labs

Understanding their origin and purpose, and studying and comparing the variety of definitions of Living Labs (objectives, settings, stakeholders) and their fields of application, we can identify the following 4 main characteristics of Living Labs:

- **Multi stakeholder approach**: often based on a PPP (Public-Private-Partnership)
- **User involvement**: giving a special role to the user as part of the innovation process
- **Open Innovation**: considering innovation as an open process with multiple stakeholders
- **Real-life environment**: experimenting and capturing user insights in real-life contexts

In the following sections, these 4 main characteristics will be analyzed and discussed in more detail.

3.2.2 Multi stakeholder approach of Living Labs

Living Labs can be understood as **innovation intermediaries**, which foster Open Innovation processes, but with a wider range of services and activities. Their special qualities lie in their capacity to **structure the participation process between multiple stakeholders** and users as well as to promote societal involvement. (Almirall 2009)

It can be seen that Living Labs often consist of **Public Private Partnerships (PPP)** having their origin at universities or city innovation centers. (Almirall & Wareham 2008) The co-creation **by users, together with researchers and other experts** allow a quicker and richer innovation process and a shorter time-to-market for products and services developed by or together with companies. **Public entities** can contribute e.g. to the access and integration of user collectives (citizens, employees, collectives)

Pallot et al. (2010) refer furthermore to the **social dynamics of the Living Lab approach**, based on the broad range and diversity of stakeholders, which participate in activities, accelerating at the same time the dissemination of the created innovations. This diversity of stakeholders is one of the essential qualities of Living Labs, although they can also be based on the initiative of a single entity, e.g. a company, a research institute or a university.

Stakeholders of Living Labs can be all type of private or public entities, like **companies, public-sector actors, non-governmental organizations, towns, municipalities, area-development organizations, educational institutes, universities, consultants, and individual users, user groups or user communities**. (Nyström et al. 2012)
Dutilleul et al. (2010) describe four typical stakeholder categories for Living Labs, namely **designers, technology specialists, researchers and entrepreneurs**.

Their **implication and interest** within a Living Lab initiative can be diverse according to their role in the overall process e.g. as drivers (see chapter 3.2.6), participants, collaborators or financiers.
A **rich and broad ecosystem of ambitious stakeholders** seems to be an essential quality and condition for the successful implementation and operation of Living Lab initiatives.

3.2.3 User involvement in Living Labs

Participation and **active involvement of users** in innovation processes are the very basic ideas behind the Living Lab approach. User and societal involvement must be defined and managed in order to integrate them into the innovation process carried out by companies or research institutions. Living Labs can facilitate the mechanisms and provide the **organizational structure** for this integration. (Almirall & Wareham 2008)

User-centered research

The role of the user in innovation processes has increased significantly in the last 30 years. Challenges in this context are to **structure this user involvement**, to **capture the user's insight** in a real life environment and to choose and apply corresponding methods and techniques.

Traditional innovation processes limited to public or privately driven innovation activities, with a long way from basic and applied research and prototype development to market studies and implementation, show to be slow processes. They do not correspond to today's fast *technological progresses* and the need for quick innovation and changes in our society.

Emerging innovations need to get into contact as early as possible with real users within a real life environment in order to explore their acceptance, improve their performance and optimize their design under real conditions. Living Labs are **places to foster user-centered research**, but also to go beyond user observation or inquiry regarding new products or services, **towards an active user participation** in innovation through co-creation processes.

Mulder et al. (2008) describe the Living Lab concept as a way of moving research and development from laboratories into real-life environments in order to test innovations within its **social, environmental and cultural context** and highlight the role of Living Labs as **networks of people** with a variety of rich backgrounds, who collectively drive innovation processes. These **social and cultural experiences** regarding innovations and the **measurement of user behavior** on a large scale would be the essential qualities that Living Labs can contribute to the innovation environment. (Mulder et al., 2008)

Many of the first Living Lab projects and an increasing number of current Living Lab activities are related to **information and communication technologies** applied to **social innovation**:

> *"The Living Lab concept seems appropriate to study questions related to the design and evaluation of innovative technology and intellectual environments that improve and enrich everyday life. The user experience focus involves areas of user interface design and ergonomics as well as user acceptance, extending to user co-design process, finally leading to service or product creation."* (Mulder, Velthausz, & Kriens, 2008)

User interface design, user acceptance evaluation and user co-design are mentioned as possible contributions of the Living Lab concept to innovation processes. (Mulder, Velthausz, & Kriens, 2008)

In this context the **rapid development of ICTs and social networks** are essential factors, which contribute to increase the velocity of deployment of Living Lab methods, activities and organizations. User participation and feedback can be handled and outcomes can be filtered much more efficiently. Communication between many different stakeholders can be done in a smart way.

As represented in Fig. 3.1, Living Labs allow users to be integrated in different steps of the innovation process, **bridging the gaps** between **first applied research, service and product development, and prototyping** until market readiness. (European Commission 2009)

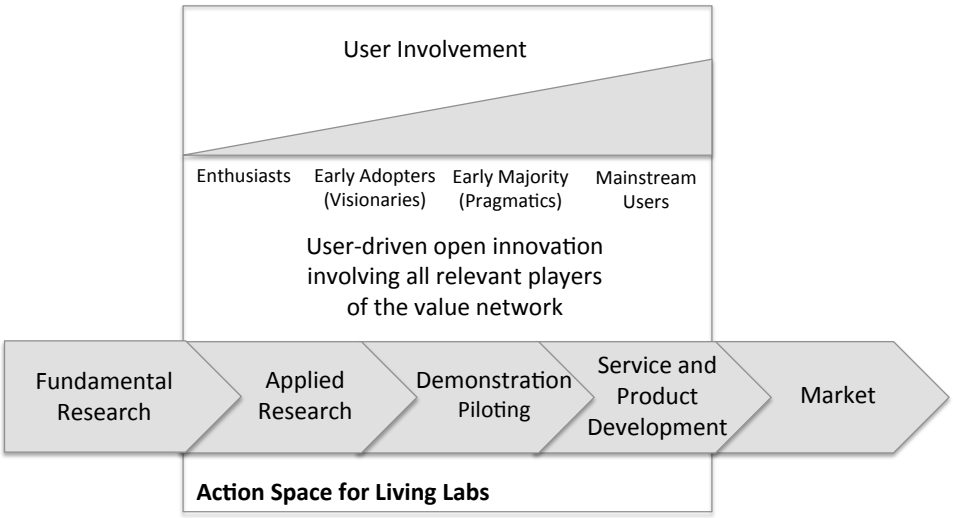


Figure 3.1 Role of users within Living Labs along the technology adoption cycle (adapted from European Commission (2009, p. 8)

This new role of the user, getting increasingly active within innovation processes converts them **from observed users to participants and even drivers of innovation**, co-creating new products or services through a multi-stakeholder approach in real-life settings.

User co-creation

Co-creation is based on the **application of methods and tools** that integrate end-users and other stakeholders in the innovation process of new products and services. The approach is directly linked to the concept of **open innovation** (chapter 3.2.3.3), which refers to the use of external resources for innovation through opening up the innovation process to external stakeholders.

Co-creation is based on the fact that, besides being observed subjects in functional tests, users can also contribute and create value though **active participation within the innovation process**. (Pallot, et al 2010).

The interaction or **co-creation between researchers, users and other participating stakeholders** is the basic process of a *Living Lab*. Nevertheless one important issue is how to filter user ideas and how to prepare the output, so stakeholders may use it for innovation. As there is no common methodology or easily applied manual for Living Labs, methods and tools vary according to the type and objectives of each Living Lab activity.

This seems to influence the effective realization of user co-creation processes as shown by Mulder & Stappers (2009): Based on extensive case studies and literature review they state that

operative Living Labs mainly use traditional methods and tools for interacting with their stakeholders across product and service innovation processes, and conclude that many Living Labs do not benefit from promising Living Lab methodologies. Additionally, industry and academia would still apply user participation as an *after-the-fact testing* activity with users evaluating finished prototypes of products or services, whereas the participation of users in earlier stages would be important in order to develop concepts of products and services that correspond to the requirements and needs of target groups. (Mulder & Stappers 2009)

Beside traditional approaches (i.e. Interviews, Focus Groups, Participatory Design, Workshop with Customers, Prototype Testing, Field Trials) the use of methods based on **Collaborative Work Environments** (CWE) (i.e. Online Creativity Groups, Dynamic Social Network logging, Virtual Prototype Tests or User Toolkits) are identified as important in order to **widen the capacities of co-creation** in Living Lab environments. (Mulder & Stappers 2009)

These ICT based methods and tools might also allow a **better understanding of the context** to all participating stakeholders in the co-creation process, as products and services are today embedded in an environment of increasing complexity.

Treating the user as the main element of a co-creation process in a living lab environment, technological developments like **online platforms, and smart phones** as well as **social networks** increases the role of users even more through the possibilities of **open sourcing or crowdsourcing**. This allows the extension of the living lab approach from **a physical to a virtual real-life context**. (Westerlund et al. 2011)

The following graphic (Fig. 3.2) compares various methodological aspects of the Living Lab approach to other forms of research regarding user **participation and context** of innovations according to Prof Otto Scharmer (MIT, CKIR). (as cited by Eriksson et al. 2005, p. 7))

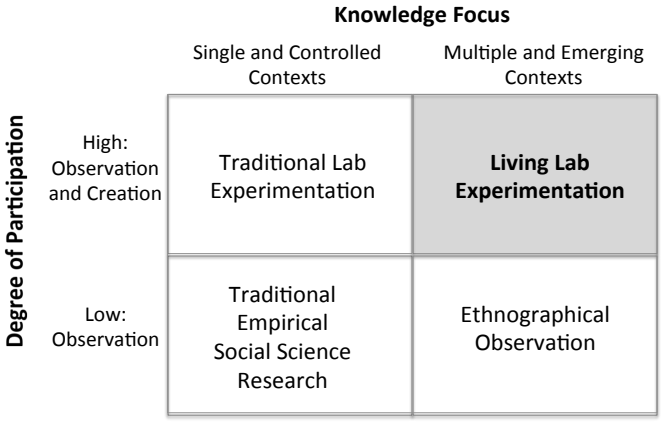


Figure 3.2 Living Labs and innovation paradigms according to Sharmer (as cited by Eriksson et al. 2005, p. 7)

Living Labs offer a research environment with a **high degree of participation** beyond the user observation of traditional empirical social science or ethnographical observation, e.g. user co-creation. Additionally Living Labs are situated in **multiple and emerging contexts**, beyond the single controlled contexts of traditional laboratories, allowing a **human centric approach** in real-life settings. (Fig. 3.2) (Eriksson et al. 2005)

Motivation is another key issue in user participation. How a user community can be contacted, selected, involved as active part of an innovation process, and what are the incentives of his participation, are major questions to be solved in this context. Motivation of participants is crucial as **continuity** is an important quality in iterative user-centered innovation processes based on Living Labs because a **stable stakeholder and user community** contributes to successful operation.

Degree of user participation

From an organizational point of view focused on innovation through Living Labs within ICT companies, Westerlund et al. (2011) describe 4 steps towards innovation driven by users:

From an initial, ***producer driven innovation*** approach (step 1), with little or no communication or interaction with users, understanding them as customers, innovation culture can evolve towards ***user-centric, closed innovation*** (step 2), where user ideas get collected through surveys and user studies, but also through the pilot testing of new products. Nevertheless, knowledge and information maintain strictly inside the organization.

A next step is defined as ***user-centric, open innovation*** (step 3), with companies considering users as an important source of information, involving them in part of the innovation process through co-creation, critical feedback and suggestions for further improvements. Nevertheless the user is not involved over the full innovation process lifecycle.

Finally a ***user-driven innovation*** approach (step 4) has been identified, where customers lead the development work in an open way. Procedures for user involvement and value co-creation are established within the company and form part of its innovation culture, with a need to manage increased openness and all related issues, such as intellectual property rights, the unpredictability of outcomes and the need of new managerial tools. (Westerlund et al. 2011)

This distinction shows the different degrees that user participation can have in innovation processes, ranging from **user observation, user participation, up to user co-creation and user-driven innovation.** Westerlund et al. (2011) refer specifically to companies in the ICT sector, but this basic distinction of levels of user participation can be applied to any kind of Living Lab approach and any kind of driver, e.g. universities, public institutions or mixed communities of drivers and stakeholders.

Understanding **innovation as a design process,** a similar distinction of levels of user involvement can be described as the transition from **design for users** through **design with users** to **design by users**. (Kaulio, cited by Schuurman & De Marez 2009)

Physical versus virtual Living Labs

Living Labs are mostly physical places where people meet, explore, experiment, evaluate and interact within an open innovation process focused on user-involvement and multiple stakeholder participation. ICT has an important role within this processes, fostering communications, evaluation and analysis of results. The immense velocity in technological innovations related to ICT's together with the very origins of living labs, focused basically on ICT development, conduct automatically to a future vision of virtual living labs linked to physical ones, merging virtual and real world environments into a complementary innovation scenario open for a networking from local up to a global scale.

Examples like the university-based **Botnia Living Lab**[29] in Sweden with more than 6000 co-creative users virtually associated is one example of a successful merge between physical and virtual Living Lab infrastructures.

A critical view on the role of the users

The involvement of users in user co-creation and innovation processes is not free of conflict. From a **functional, ethical and motivational** point of view, users are not as easy to integrate in innovation processes as other stakeholders with defined roles and specific interest in project, like companies, researchers or other experts.

Dutilleul et al. (2010) e.g. are critical in their view on user participation and the generally high expectation of their contribution to the innovation process. They question the **qualification of users** for that ambitious task regarding their knowledge and skills and also their willingness to contribute to a process without a compensation or formal involvement in the innovation organization. They doubt the possibility of "putting the user in the driver's seat" (European Commission 2009, p.8) given that driving innovation processes requires **specific skills and knowledge** regarding technology, organization and business, that users generally do not have. (Dutilleul et al. 2010)

Dutilleul et al. (2010) propose limiting the interpretation of *users as drivers* to giving users' evaluation criteria mayor attention, above those of other stakeholders, although this would also require specific control of the whole process, as users have limited knowledge of innovation and product development processes.

Summing up, it seems that positive and negative views on user involvement in our changing society are somehow balanced: On the one hand are the expectations about the so-called **democratization of innovation** (von Hippel 2009) and the first successful examples of user co-creation; on the other, there is a more critical view referring to an **over expectation of user contribution** and a temporary hype which wrongly understands the **user as a "free resource"** for innovation.

[29] http://www.ltu.se/centres/cdt/Vart-erbjudande/Experimentmiljoer/Botnia-Living-Lab-1.111199?l=en

Conclusions

Living Labs provide organizational structures for the transition from traditional user-centered research to the **active involvement of users in innovation** processes. (Almirall & Wareham 2008)

This happens best within a real-life **social, environmental and cultural context,** benefitting from the role of Living Labs as **networks of people** with a rich variety of backgrounds, who collectively drive innovation processes contributing through their diverse **social and cultural experiences.** (Mulder et al., 2008)

The **rapid development of ICTs and social networks** along with the development of efficient tools to capture, filter and communicate smartly generated user insights, contribute significantly to the deployment of Living Labs. (Mulder, Velthausz, & Kriens, 2008)

The new role of users converts them from **observed users** to **participants** and even **drivers of innovation processes.**

Co-creation between researchers, users and other participating stakeholders requires the application of **living lab specific methods and tools**, which seems to be still a weak point in many projects due to a missing common methodological framework. (Mulder & Stappers 2009)

ICT technologies will foster the role of the user, e.g. through open sourcing or crowdsourcing, and allow the extension of the living lab approach from **a physical to a virtual real-life context**. (Westerlund et al. 2011)

Degrees of user participation can be described as ***producer driven innovation; user-centric, closed innovation; user-centric, open innovation*** and ***user-driven innovation.*** (Westerlund et al. 2011) Accordingly the design process of a product or service can be described as **design for users, design with users** or **design by users**. (Kaulio, cited in Schuurman & De Marez 2009)

Finally, user involvement can be critical from a **functional, ethical and motivational** point of view, due to a possible lack of skills, knowledge and eventually motivation of users, as well as an over expectation of their contribution and their consideration as a "free resource". (Dutilleul et al. 2010)

3.2.4 Open Innovation in Living Labs

Open innovation first appeared as an **alternative concept to closed "in house" innovation** approaches, which in the 1990's already evolved in their structure and process through the introduction of technology platforms, clusters, innovation centers or incubators, but, due to the increasing velocity and diversity of technological developments, still showed to be limited in their capacity to quickly generate cost-efficient, market-ready innovation,.

Open Innovation

Chesbrough (2003) introduced the term of Open Innovation describing the **collaboration between internal R&D departments with external partners**, benefiting from the synergies generated within a structured collaboration process. (Schuurman et al. 2013)

Regarding living labs and their relation to innovation, Schuurman et al. (2013) describe two different approaches of distributed innovation: **open innovation** and **user innovation** (citing Bogers and West (2012)). Whereas open innovation refers to the collaboration of firms with external agents in order to accelerate their own innovation processes through external partners, user innovation refers to distributed innovation processes from the perspective of the user.

In this context von Hippel (2009) refers to the improved design capabilities of users through computer hardware and software, as well as new communication media like the Internet, as main drivers for a growing ***democratization of innovation***.

Chesbrough (cited by Almirall & Wareham 2008, p. 24) highlights the importance of **innovation intermediaries** in open innovation processes and classifies them as agent, broker or marketplace. For Almirall (2009) **heterogeneity** is both the objective and a prerequisite for innovation, as differentiation from others is one of the main objectives of innovation, e.g. for a company regarding a better product or service. In this sense the Open Innovation approach promises to contribute to an improvement of innovation processes through the **joint effort** of multiple stakeholders, legally based e.g. on collaboration agreements.

Nevertheless Open Innovation linked to co-creation processes is not free of conflict. **Intellectual property rights, conflicts of interest** among participants or simply issues of personal **trust** among stakeholders regarding the common goals or strategies can generate disagreements, which can make the whole process difficult.

Open Innovation in Living Labs

Open Innovation can be one strategy or methodology to apply in Living Labs, as the open character of the Living Lab concept favors the integration and participation of multiple stakeholders. The approach is included in some Living Lab definitions (Pallot et al. 2010, Mulder & Stappers 2009) as a characteristic parameter, although others do not refer to this radical new type of innovation.

Schuurman et al. (2013) propose **living labs as a common place** where both forms of distributed innovation processes, **open innovation** and **user innovation**, could be brought together (Fig.3.3). These two forms of innovation would be linked through co-creation processes, as collaborative development of innovation among different stakeholders.

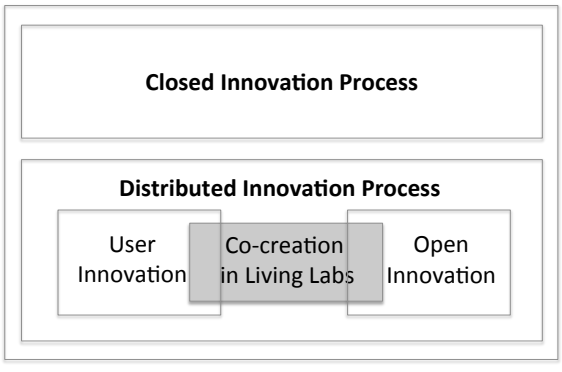


Figure 3.3 Living Labs and innovation paradigms according to Shuurman et al. (2013)

Open Innovation is closely linked to the concept of **multi stakeholder co-creation** but goes beyond the collaborative approach to innovation, referring also to the **strategic and legal framework** of collaboration among entities, e.g. companies of the same or of complementary technology sectors.

Ballon et al, (2005) define a living lab as "an experimentation environment in which technology is given shape in real life contexts and in which (end) **users are considered 'co-producers'**." (p.15)

This establishes a clear link to other forms of user participation in innovation processes like ***lead users*** or ***open source communities,*** which can adopt the role of the principal creators of innovation, whereas in the field of ***user-centered design*** users adopt a more passive role, giving insight or being observed for usability, human interaction or market validation exercises. (Almirall et al. 2012)

Open Innovation seems to be a strategy, which **fits well into the Living Lab approach,** being complementary to user-driven design and other forms of user involvement, as both are forms of distributed innovation based on the idea of **collectively generating and sharing innovation**. Nevertheless Open Innovation concepts and their organizational structures are diverse and common frameworks for applied methodologies are still under development. (Shuurman et al. 2013)

A **high degree of openness** of an innovation process leads generally to a pluridisciplinary stakeholder group with members of very different backgrounds. This enriches the process in Living Labs and widens the view towards a systemic innovation approach, but can also be a source of conflict during project development due to the **diversity of opinions, disciplinary views** and **personal backgrounds**, which influence the whole process, or **Intellectual Property Right (IPR) issues** regarding collectively generated knowledge. The careful preparation of each group of participants might be necessary in order to make them understand the overall dynamics, the methodology, rules, tools and goals of a Living Lab project. (Dutilleul et al. 2010)
The **openness of innovation processes** in Living Lab environments is not in itself a guarantee for its success, but should be planned carefully regarding the selection and correct amount of participating stakeholders.

3.2.5 Real-life environments of Living Labs

Real-life environments are the **natural setting for Living Lab projects**. People react differently in real-life environments than in laboratory situations. This is because thinking about a product, technological solution or service is considerably different to using it in real conditions, and so the outcome of user-centered research will be much more significant for the final solution. (Mulder et.al. 2008)

Therefore, real-life settings are ideal places for **testing user acceptance,** involve users in **co-design** processes and finally arrive at **product or service co-creation** amongst multiple stakeholders. Finally, Living Labs are also a **place to meet and interact** between all participants, creating synergies for efficient innovation processes based on the diverse backgrounds and experience of all stakeholders. (Mulder et al. 2008)

The concept of research and innovation in real-life environments

The real-life setting of Living Labs allows the evaluation of socio-economic aspects of new products, services or technologies at an early stage on their way to market, under the **conditions and complexity of real environments** and context. (Santoro & Conte 2010)

By testing and evaluation through users in their daily lives, more **realistic feedback** and valuable **insights** about innovations can be gathered, which cannot be provided through testing in laboratory conditions for example. (Schuurman & De Marez 2009)

> *"Living Labs [serve] for better discovering new and emerging behaviors and use patterns, as well as for assessing at an early stage the socio-economic implications of new technological solutions."* (European Commission 2009 p.12)

Operation in real-life environments is one of the essential qualities of Living Labs in comparison to other approaches to innovation.

Living Labs as Test and Experimentation Platforms (TEPs)

Living Labs are only one of a series of existing forms of testing, experimentation and innovation platforms. Based on an extensive analysis of case studies in the field of broadband innovation, Ballon et al. (2005) denominated them generically as TEPs (Test and Experimentation Platforms) and classified them according to the following 6 concepts:

- **Prototyping platforms:** *Design and development facilities used prior to mass production and resulting in the first proof-of-concept of a new technology, product or service.*
- **Test beds:** *Standardized laboratory environments used for testing new technologies, products and services and protected from the hazards of testing in a live or production environment*.
- **Field trials:** *Tests of technical and other aspects of a new technology, product or service in a limited, but real-life environment*.
- **Living Labs:** *Experimentation environments in which technology is given shape in real life contexts and in which (end) users are considered 'co-producers'.*
- **Market pilots:** *Pilot projects in which new products or services that are considered to be rather mature are released to a certain number of end users in order to obtain marketing data or to make final adjustments before the commercial launch*.
- **Societal pilots:** *Pilot projects in which the introduction of new products and services into a real-life environment is intended to result in societal innovation*

Prototyping platforms and Test beds are clearly **distanced form real-life settings**, offering a protected laboratory and test environment under controlled conditions in order to experiment and evaluate innovations. Field trials, Living Labs, Market Pilots and Social Pilots **are introducing innovations in real-life environments,** with Living Labs additionally integrating users as co-producers of innovation, beyond testing and evaluation. (Ballon et al. 2005)

With this conceptual distinction Ballon et al. (2005) attempt to enclose all facilities and **environments for joint innovation** including testing, prototyping and user evaluation, although they also indicate that **hybrid versions** can exist combining different concepts.

Limitations of real-life context

Real-life contexts are more difficult environments for assessment of products, services or technology innovations through users due to their **complexity**. Data collection and **control of factors which determine user behavior,** are more complex than in controlled environments like laboratories. Nevertheless ICT and sensor technologies evolve exponentially and contribute to overcome these shortcomings.

It can be said that the differentiation of Living Labs from other **Testing and Evaluation Platforms (TEPs),** and the understanding of the **specific qualities and limitations of real-life contexts** are important in order to understand the specific opportunities Living Labs provide for research and innovation.

3.2.6 Differentiation criteria for Living Labs

According to the variety of definitions of Living Labs (chapter 3.2.1), differences can be described in their organizational structure, regarding their legal and physical formats, their typology or their drivers, their size, their duration and their outcomes.

Types of Living Labs

Nowadays Living Labs tend to be very heterogeneous in their organization, applying many different tools and methods for managing innovation processes, organizing stakeholders and including users in their activities according to their specific objectives. Their effectiveness depends mainly on their capacity to mediate user insights and participation.

No unique organizational or business model can be described for Living Labs, but a great variety of initiatives are currently under development, and research on Living Lab methodologies and organization is continuously evolving.

In order to structure the **diversity of Living Lab approaches** and initiatives, Magdala & Pedruzzi (2013), referring to Dekkers (2011) propose differentiating between 3 types of Living Labs:

Living Lab Type I: **Physical places like prototype homes**, which are used as test-beds i.e. for the user evaluation of new technologies related to the home.

Living Lab Type II: **Organizations, which support, manage and organize innovation activities**, specifically focused on bringing together different stakeholders like researchers, companies, and public institutions in order to co-create new solutions, products, services, business models or markets together with users in real-life environments.

Living Labs Type III: **Living Labs as networks of innovation** beyond a single organization, which manage individual innovation activities.

This differentiation identifies Living Labs basically as **places,** as **organizations** or as **networks**.

Functional Categories of Living Labs

Based on an extensive literature review on the topic, Ditilleul et al. (2010) summarize the following 5 different definitions or **functional categories for the term Living Lab**:

- ***An innovation system*** *consisting of organized and structured multi-disciplinary networks fostering interaction and collaboration*
- ***In vivo monitoring*** *of a 'living' social setting generally involving experimentation of a technology*
- *An* ***approach for involving users*** *in the product development process*
- ***Organizations*** *facilitating the network, maintaining and developing its technological infrastructure and offering relevant services*
- *The term may also refer to the eponymous* ***European movement***

Nevertheless Følstad (2008) states that in practice, initiatives which are described as Living Labs adopt different characteristics of this **vague and multi-faceted concept**, and Living Lab concepts and characteristics are interpreted differently.

Drivers of Living Labs

One criterion for the differentiation of living lab concepts can be by identification of the **main driver** of such an innovation infrastructure. According to this differentiation criteria, Nyström et al. (2012) identify 4 main types of living labs:

Utilizer-driven living labs: Drivers are mainly ***companies*** *that launch and promote living labs to develop their businesses*. User experiences and information about specific products or services contribute to their development with specific results and outcomes envisioned by the companies. Rapid results are desired by the utilizers, so guided co-creation processes within limited periods are characteristic, leading to the short overall lifespan of this type of living lab.

Enabler-driven living labs: Drivers are mainly ***public-sector actors, non-governmental organizations, and financiers, such as towns, municipalities, or area-development organizations****.* The generation of a platform for the collaboration of key actors, for example in regional development processes, is one of the aims of an enabler-driven living lab. This type of public-sector projects for societal improvements often include universities as stakeholders and build on long term collaborations and the generation and sharing information, often within regional development programs. Companies however seem to have only a marginal participation in this type of living labs due to a lack of potential business benefits.

Provider-driven living labs: This type of living lab is generally *launched as a result of actions by various* ***developer organizations such as educational institutes, universities, or consultants****.* It is about establishing an open-innovation network where all participants benefit from the generated knowledge and information. Universities for example use living labs for educational research and innovation in teaching methods. Nevertheless, it might be difficult to include enablers and utilizers into this type of innovation platform, as companies demand specific results in a limited time.

User-driven living labs: These kinds of living labs are *established by **user communities** and focus on solving users' everyday-life problems*. User-driven living labs are based on a community of users, informally organized, which co-create solutions for common problems, e.g. as a local housing community. Resources, infrastructure, equipment and even knowledge and guidance is given by a provider, not by the users themselves and due to the bottom-up approach, management as a specific infrastructure is difficult.

According to these **4 categories**, developed by Nyström et al. (2012), the main character of a living lab can be identified through the identification of the main driver, although by far not all living lab initiatives can be clearly attributed to one of the developed categories, as main stakeholders are often a mixture i.e. of enablers, utilizers and providers.

Others change over time, and the initial leader gives over control to a different type of driver. Nevertheless the identification of the type of main driver of a living lab initiative and the resulting project specific characteristics help to understand the **potential and the limitations of each approach** and contribute to analyze and understand applied methodologies, tools, and outcomes.

Regarding drivers of Living Labs, Almirall & Wareham (2008) state that many Living Labs have their origin in either **university technology transfer organizations or city innovation centers**, and that their specific novelty is not so much related to their organization but to the integration of users as actors.

The size of Living Labs

Size of Living Labs can vary widely according to the dimension of the underlying projects, stakeholder networks and real-life environments chosen for the corresponding activities.
Ballon et al. (2005) consider scale as one of the important characteristics of Testing and Experimentation Platforms (TEPs), a concept that includes Living Labs.

Regarding the size of Living Labs, Veeckman et al. (2013) propose a differentiation according to the **number of users involved** in a Living Lab initiative, also referred to as living lab panel. They define an initiative with less than 100 users involved as small-scale, and with more than 500 users involved, as a large-scale Living Lab.

From the point of view of infrastructure, Living Labs can range from **small-scale laboratory** like environments for testing a specific product or service by individual users, up to an **organization with several thousand users** of a region, i.e. Botnia Living Lab[30], an environment in Sweden for human-centric research and the development, with a community of more than 6000 users, which participate in the evaluation of innovative ICT based solutions.
On a larger scale, whole **cities** define themselves recently as Living Labs for experimentation, i.e. for smart city technologies regarding mobility, energy or ICT infrastructure, i.e. the Barcelona 22@ district Living Lab[31] or Paris Smart City Living Lab[32].

[30] http://www.ltu.se/centres/cdt/Vart-erbjudande/Experimentmiljoer/Botnia-Living-Lab-1.111199?l=en
[31] http://www.22barcelona.com/content/view/46/430/lang,en/ (accessed July 2015)
[32] http://www.smartcity.fr/europe/en/ (accessed July 2015)

Finally **European regions** are beginning to network between themselves, i.e. within Living Lab networks like the European Network of Living Labs (ENoLL)[33] or for specific collaboration purposes. (Eriksson et al. 2005)

The Lifespan of Living Labs

Another differentiation criteria for living labs can be the lifespan of a specific living lab project or of the living lab as innovation platform or innovation ecosystem itself.

Veeckman et al. (2013) describe Living Lab initiatives with a duration of less than 6 months as short-term and those with a duration of more than 2 years as long-term, whereas initiatives without an end date are described as very long-term.

Naturally, the lifespan of a Living Lab initiative depends on too many factors to be able to establish categories or estimated values for specific types of initiatives. Only general considerations can be made, e.g. according to Nyström et al. (2012) a provider-driven living lab is much more short term oriented, due to the fact that the main driver of the project is a company which generally plans in shorter innovation cycles and has specific objectives within a limited time-frame, in order to generate the expected outcomes and introduce the results into their economic activities as soon as possible, generating profits. Six months might be even too long-term for that kind of company.

Living Lab outcomes

According to Pallot et al. (2010) users can generate valuable outcomes through experimentation and evaluation of certain products, services, technological artifacts or scenarios within real-life environments on three different levels:

- The socio-economic level (societal, environmental, health and energy cost/value)
- The socio-ergonomic level (user friendliness) and
- The socio-cognitive (intuitive level) together with insights about the acceptance and adoptability (potential level of viral adoption)

How to **filter user contributions** and **guarantee validity of results** for the innovation process is one of the important issues, which characterize user participation and innovation processes.

Schuurman et al. (2013) give additionally importance to the **retention of the generated knowledge** in Living Labs referring the accumulation and re-use of knowledge if different projects are carried out under the same specific thematic focus.

Conclusions

Living Labs can be differentiated through their **type and amount of stakeholders**, often being based on a **Public Private Partnership (PPP)**.
Main drivers of a Living Lab can be distinguished as **utilizers, enablers, providers and users** (Nyström et al. 2012) resulting in differences regarding, approach, methodology, objectives and outcomes.

[33] http://www.openlivinglabs.eu (accessed July 2015)

The **term Living Lab has been used broadly** in recent years for the description of a variety of activities, strategies or projects at different scales. The term Living Lab can refer, for example, to a **methodology** applying a set rules and strategies to a process of innovation. A Living Lab can also describe an **infrastructure** which consists of a physical or virtual place, and which allows to apply Living Lab methodologies, methods or practices. Finally a Living Lab can refer to a **whole project or initiative**, e.g. a whole research and innovation infrastructure, network or ecosystem, including its management, its organizational structure, its tools and equipment.
Size and duration of a Living Lab can be diverse, ICT applications and distributed settings in real-life environments allow the integration of large communities of users and stakeholder networks. Duration depends on the individual focus of each project.
User participation generates valuable outcomes through **insights on a socio-economic, socio-ergonomic and socio-cognitive level**.
Understanding the **differentiation criteria** of Living Labs, identifying for example their type, functional category or main drivers, helps to design or join the right model of Living Lab for a certain kind of innovation project.

3.2.7 Holistic evaluation of the living lab approach

Based on Schuurman & De Marez (2009) and adapted though own research, the following SWOT analysis shows the basic strengths and opportunities as well as weaknesses and threats for the Living Lab concept.

Strengths	**Weaknesses**
User involvement	Can be time- and budget consuming
Real-life environments	Drop-out risk of participants
Large user groups	Reliability of data
Can be cost-efficient	Lack of studies and experiences
Can generate future market	
Opportunities	**Threats**
Cooperation opportunities	Depends on external funding
Raising awareness	Other Test and Experimentation Platforms
User feedback	European lag
Potential of Web 2.0 and ICT	Lack of business models

Table 3.1 SWOT analysis of the Living Lab concept, based on Schuurman & De Marez (2009) and own research

Regarding the **strengths** of the Living Lab approach, **user involvement** is the most fundamental, allowing the generation of valuable insights for innovation, and even user participation in the design process of a product or service. Testing and evaluation in **real-life environments** allows realistic context related feedback and data. If a distributed Living Labs approach is used, **large user groups** can be involved in a **cost-efficient** way, constituting at the same time part of a possible **future market** e.g. for a specific technology or product.

Regarding **weaknesses,** Living Labs can constitute a **time- and budget consuming** concept, for example due to the infrastructure necessary for capturing user insights in real-life environments or the high number of stakeholders which participate in Living Lab projects. **Users** as participants

of the process can **drop out** for various reasons, e.g. if during long testing and evaluation periods, their motivations or personal circumstances change over time. **Reliability of data** is another issue and depends on the right amount and profile of user groups participating and the right design and execution of the experiment. Living Labs still suffer a **lack of studies** regarding their theoretical framework as well as the documentation of **experiences**. (Schuurman & De Marez 2009)

Opportunities for Living Labs include **cooperation** among multiple stakeholders, helping to create pluridisciplinary research teams and a stronger link among public and private actors as well as citizens (people) through public private people partnerships (PPPP). Large stakeholder groups and user participation guarantee **raising awareness,** for example regarding emerging technologies. **Web 2.0 applications** increasingly support cooperative and co-creative communities and have the potential to change our ways of learning, working and collaborating. **ICT technologies** in general will allow the capturing, filtering and increasingly detailed use of **user feedback**.

The threats of the Living Lab approach are the **dependence on external funding**, as a living lab infrastructure, organization and network of stakeholders and users need to be maintained e.g. in the time between competitive, financed projects. **Other Test and Experimentation Platforms (TEP's)** might be more economic as well as easier to use and maintain. A **lack of business models** and a **European lag** in comparison with other markets might be considered as additional threats to the concept of Living Labs. (Schuurman & De Marez 2009)

3.2.8 Summary and conclusions

An introduction to the **existing conceptual framework** of Living Labs has been given with a **state of the art review** of living lab research regarding definitions, objectives, types and characteristics of this specific approach to innovation.

In its basic **definition,** Living Labs **"involve users in the innovation process by designing, developing and validating new technologies, products and services within real life environments"** (Almirall, 2008, p.22).
Nevertheless due to the **ambiguity of the concept**, based on an extensive literature review 10 different definitions of Living Labs have been selected, stating that the term Living Labs can refer to a **research and innovation methodology**, to a **physical place or infrastructure**, or to an **innovation network or ecosystem**, with corresponding frameworks currently emerging through on-going theoretical research and field experiences of a growing number of projects.

The **applicability** of the Living Lab approach is open to any discipline, which benefits from user involvement in innovation processes. **Sectors of application** e.g. regarding ICT solutions are **e-Health, Ambient Assisted Living, e-Inclusion, e-Transportation, e-Government, Smart City, ICT for Energy, and ICT for Environment** (Pallot et al. 2010) among many other fields which can benefit from this approach to technological or social innovations.

Four main concepts have been identified as specifically relevant and characteristic for Living Labs: A **multi stakeholder approach**, often based on a PPP (Public Private Partnership), **user involvement**, giving a special role to the user as part of the innovation process, **Open**

Innovation, considering innovation as an open process with multiple stakeholders, and operation in **real-life environments**, experimenting and capturing user insights in real social, environmental and cultural contexts. (Mulder et al., 2008)

Stakeholders of Living Labs can be all kinds of public or private entities like **companies, research institutes, universities and other public or private institutions** (Nyström et al. 2012) with **designers, technology specialists, researchers and entrepreneurs** as typical participants categories. **(**Dutilleul et al. 2010)
Living Labs can be understood as **innovation intermediaries**, which **structure the participation process between multiple stakeholders** (Almirall 2009), often based on **Public Private Partnerships (PPP)**, creating and managing rich and pluridisciplinary innovation ecosystems.

The **active involvement of users** in innovation processes is the very basic idea behind the Living Lab approach. User involvement is described as the **measurement of user behavior** on a large scale (Mulder et al., 2008), **user interface design, user acceptance evaluation and user co-design** (Mulder, Velthausz, & Kriens, 2008) and the integration of users as innovators from **first applied research, service and product development until prototyping** (European Commission 2009). Living Labs are considered places for user co-creation in multiple and emerging contexts with a **human centric approach** (Eriksson et al. 2005). User involvement in innovation processes can range from **user observation,** through **user participation** to **user co-creation** and finally **user-driven innovation** (Westerlund et al. 2011), also described as **design for users, design with users** and **design by users**. (Kaulio, cited by Schuurman & De Marez 2009)**.**

ICT technologies and applications like **online platforms, smart phones** as well as **social networks** allow the role of users to be strengthened even more e.g. through **open sourcing or crowdsourcing** and the extension of the living lab approach from **a physical to a virtual real-life context**. (Westerlund et al. 2011) Nevertheless user involvement can be seen as critical from a **functional** (limited skills and knowledge of users), **ethical** (considering users a "free resource") and **motivational** (continuity of participation) point of view. (Dutilleul et al. 2010)

Open Innovation is described as the **collaboration between internal R&D departments with external partners** and synergies as well as conceptual similarities are reported as **User Innovation** within the co-creation approach of Living Labs; both are distributed forms of innovation. (Schuurman et al. 2013) **Open Innovation strategies,** focused on **collectively generating and sharing innovation,** seem to **fit well into the Living Lab approach**, although a high degree of openness can also be critical regarding **diversity of opinions, disciplinary views** and **personal backgrounds** as well as **Intellectual Property Right (IPR) issues.**

Real-life environments are the natural setting for Living Lab projects as places for **testing user acceptance, collecting user insight** and **user co-design,** under the **conditions and complexity of real contexts** (Mulder et al. 2008, Santoro & Conte 2010)

Similar **Test and Experimentation Platforms (TEPs)** are reported such as **Prototyping platforms, Test beds, Field trials, Market pilots or Societal pilots**, establishing criteria of distinction (Ballon et al. 2005), referring also to the **specific limitations of real-life contexts** regarding data collection, experimental control and the complexity of the environment.

Differentiation criteria for Living Labs have been discussed referring, for example, to their definition as **physical places** (e.g. prototype homes), **organizations** (supporting, managing and

organizing innovation activities) or **networks of innovation** (beyond a single organization). (Magdala & Pedruzzi (2013), referring to Dekkers (2011))

Main types of drivers of a Living Lab can be distinguished as **utilizers, enablers, providers and users** (Nyström et al. 2012) resulting in differences regarding, approach, methodology, objectives and outcomes, being **university technology transfer organizations or city innovation centers** often the driving force behind them. (Almirall & Wareham 2008)

The **size** of Living Labs can range from **small-scale laboratories** to **organizations with several thousand users,** or **even cities** or **regions, and lifespan** can range from short to long term, according to each initiative's objectives and individual conditions.

Outcomes of Living Lab initiatives can be **user insights on socio-economic, socio-ergonomic and socio-cognitive levels** together with information about **user acceptance and adoptability**. (Pallot et al. 2010) Nevertheless user contributions must be filtered in order to guarantee their validity and applicability in the innovation process. **Retention of knowledge generated** can allow its re-use, creating expertise in Living Labs with specific thematic focus. (Schuurman et al. 2013)

Due to their unique concept, **Living Labs** have specific **strengths** (user involvement, use of real-life environments, large user groups, cost-efficiency if ICT based, generation of future markets) and many **opportunities** (cooperation, awareness raising, increasing possibilities to capture user feedback, the development of Web 2.0 applications and ICT), but they also have **weak points** (they can be time and budget consuming, drop-out risk of participants, reliability of data, lack of studies and experiences) and **threats** (depends on external funding, competition with other Test and Experimentation Platforms (TEPs), European lag, lack of business models). (Schuurman & De Marez 2009 and own research)

Living Labs have a certain **complexity** in their organization due to **the integration, management and evaluation of user contribution to innovation processes** (user group management, filtering of valid outcomes, context awareness), **their openness** (IP issues, multi stakeholder approach) and their **applied methods and tools** (ICT infrastructure and tools which rapidly evolve), but are an interesting **option for specific areas of innovation**. Research on Living Labs is ongoing and conceptual frameworks are constantly evolving.

3.3 Living Labs in Architecture – an approximation

In the following discussion, a **specific interpretation** of the generic concept of Living Labs (see chapter 3.2) is offered for the **discipline of Architecture**. Although an increasing number of projects in the fields of prototype architecture, evaluation of buildings under real occupation or technology test beds for energy efficient technologies include the term Living Lab in their description, there are only a few items of literature available about how the Living Lab approach can be translated to the field of Architecture and what would be the specific characteristics, types, drivers, fields of application, stakeholders and applicable methods and tools.

Delimitations between prototype buildings and Living Labs in Architecture is somehow undefined, with many pilot buildings exhibiting a user-centered approach regarding use and evaluation, but without including co-creation activities or a multi-stakeholder approach to innovation. This chapter contributes to the **clarification of the concept of Living Labs in Architecture.**

3.3.1 Introduction into the concept of Living Labs in Architecture

Origins of the term

Living Labs in the field of Architecture today have their origins in research and innovation in the field of **architecture laboratories** on one side, and **prototype architecture** on the other.

Chapter 4.2 describes the historical development of architecture laboratories and prototype buildings towards so-called Living Labs in Architecture through the detailed description of 25 historical projects and a discussion about the main focus of innovation in each decade from the 1920's onwards until the turn of the 21st century. Projects are mostly linked to **research and education activities at universities** and focused on the testing and evaluation of **new building typologies, construction systems, energy systems and energy efficiency concepts.**

Technological innovations as well as **political, economic and societal developments** influenced the research focus, funding opportunities and impact of different types of laboratories and prototype projects during the 20th and beginning of 21th century, together with the definition of the Living Lab approach at the end of the 1990's, which resulted ultimately in the appearance of what can be described **Living Lab projects related to Architecture** or **Architecture Living Labs.**

Purpose of Living Labs in Architecture

Architecture Living Labs are settled at the **intersection of Living Labs** on one side **and Prototype Architecture and Architecture Laboratories** on the other (Fig. 3.4).

They arise either when the Living Lab approach is implemented within an architectural context (e.g. existing buildings or people's homes) or when Prototype Architecture or Architecture Laboratories are opened up to the user, involving him in testing and innovation activities within

a social context (prototype buildings for real clients and users) or a research context (prototypes or laboratories simulating real-life contexts).

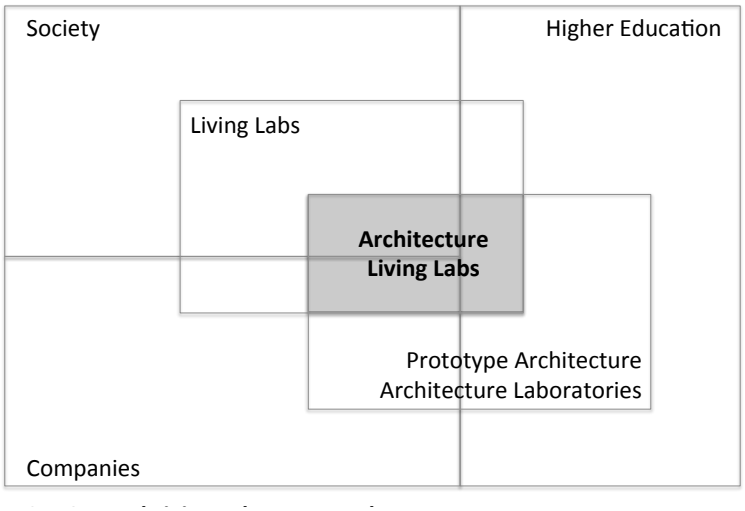


Figure 3.4 Architecture Living Labs as intersection of Living Labs and Prototype Architecture / Architecture Laboratories

As in all kind of Living Labs, its purpose is to **strengthen the role of the mainstream user** in applied research, prototyping and the development phases of products or services, through early **user insights, user feedback or user co-creation** in real-life contexts, in order to cross the "pre-commercial gap" of innovations. (European Commission 2009)

Definitions of Living Labs in Architecture

Architecture Living Labs are based on the same definitions as all type of Living Labs, They can be described as **open innovation environments** (Mulder & Stappers 2009)**, experimental platforms** (Schuurman & De Marez 2009) or **open innovation ecosystems** (Pallot et al. 2010), with the objective to **study users in their everyday habitat** (Schuurman & De Marez 2009) and **co-create and test innovations** collectively with users and stakeholders. (Nyström et al. 2012)

The settings are defined generally as **real-life or real-world environments** ((Almirall & Wareham 2008, Feurstein & Hesmer 2008) which can be translated in research environments based on real buildings or built environments like **prototype apartments and houses, or existing buildings and homes of people.** Additionally **nearly real-life environments** can be contemplated as Living Labs, simulating office space, or parts of a home within a controlled laboratory environment in order to test and evaluate technologies, products or services with users. In this case the limits between test beds and Living Labs are not clearly defined.

Sectors of application

Architecture Living Labs can be used as innovation environments for all kind of **technological or social innovation ideas** related to **living and working environments**, and specifically for all aspects related to **housing.**

Understanding the **importance of users and their behavior** in the context of sustainable development leads to considering them as an important part of the innovation process especially in fields like **energy efficiency, user-building interaction and sustainable life style**.

The following principal **sectors of applications** for Architecture Living Labs can be identified:

- Sustainable building concepts
- Energy efficiency
- Energy management
- Sustainable Lifestyle
- Sustainable Consumption
- Social Innovations
- Behavioral change
- Connectedness

Specific **areas of innovation** may be:

- New standards for housing (Nearly Zero Energy Buildings (NZEBs), Energy positive Buildings, Carbon neutral Buildings)
- New typologies of housing (e.g. co-housing, intergenerational living, emergency housing, minimal housing units)
- ICT technologies applied in homes (e.g. e-Health, Ambient Assisted Living, Internet of Things, User-Building interaction, Working environments at home)
- Design (Design for behavioral change, design for resource efficiency, design as support for a more sustainable lifestyle)

As most of the unsustainable impacts that are generated by society are related **to our built environment and specifically to housing**, prototype homes used as Living Labs seem to be perfect environments to generate, prototype, test and implement related innovations, evaluating them with users under real-life conditions. This can refer to all types of **concepts, technologies, products, materials, services or behavior changes** which could contribute to a reduction of this impact.

Main characteristics of Architecture Living Labs

In understanding their origins, purpose, the variety of definitions and the fields of application of Architecture Living Labs, the same four main characteristics of the general Living Lab approach can be described as significant:

- **Multi-stakeholder approach**: often based on a PPP (Public-Private-Partnership)
- **User involvement**: giving a special role to the user as part of the innovation process
- **Open Innovation**: considering innovation as an open process with multiple stakeholders
- **Real-life environment**: experimenting and capturing user insights in real-life contexts

In the following paragraphs these four main characteristics will be analyzed and discussed in more detail for the specific application of Living Labs in Architecture.

3.3.2 Multi stakeholder approach of Architecture Living Labs

Architecture Living Labs understood as prototype buildings or similar research and testing facilities allow easy integration of a **transdisciplinary approach,** bringing together stakeholders of **different disciplines and sectors**.

The **building sector** in general and especially housing is deeply related and partly responsible for the environmental impact of our lifestyle and therefore **concepts, materials, products, systems and services** related to buildings and the way we live in them are key for a more sustainable development in our society. Research on housing and sustainable lifestyle includes disciplines such as **sociology, psychology, biology,** all types of **engineering disciplines, environmental sciences, physics** as well as **design, architecture** and all related **creative disciplines.**

This pluridisciplinary multi stakeholder approach in the field of Architecture can be initiated, organized and driven through Architecture Living Labs, typically based on **Public Private Partnerships (PPP)**, often having their origins in universities, innovation centers or companies of the building sector. Other stakeholders can join, for example **non-governmental organizations, towns and municipalities** with interest in **promoting sustainable housing and lifestyle** among their population.

3.3.3 User involvement in Architecture Living Labs

Technological developments or legislations by themselves cannot **change human habits and behaviors** towards a **low impact lifestyle** as quickly as necessary. The **users (citizens)** themselves are important **drivers of change** as all related technological and social innovations must be accepted and fully embedded in society in order to be a successful contribution to a higher degree of sustainability. Living Labs can provide the organizational structure for the involvement of users (Almirall & Wareham 2008).

User-centered research

Historically the assessment of building performance has been done through user inquiries and the collection of user insights through personal interview with the inhabitants. User observation in built environments has allowed the collection of data about the use of spaces. Nowadays the **measurement of user behavior** on a large scale is the essential factor that Living Labs can contribute to the innovation environment (Mulder et al., 2008). This can be introduced through detailed user observation e.g. within a prototype home in order to monitor the use and interaction with spaces, technologies and installations.

User co-creation

The concept of the **user as producer of technological or social innovations** and the importance of **user acceptance** and **market viability** for the successful introduction of sustainable innovations requires the need to embed innovations into the social context in early stages of design in order to make common **tests** (lead users, mainstream users), to **further develop** (user co-creation, user-driven design) and finally **implement** new solutions (user groups as future markets).

Users in Architecture Living Labs can participate in the design process through the evaluation of technologies and installations of a home, or through feedback about the functional or spatial concept of a house, by living in a prototype for a certain period or through testing technologies in their own home environment.

Degree of user participation

As defined in the general definitions of user participation in Living Labs, the user can adopt different roles. He can be observed as a subject, or participate in the co-creation process, or even drive the innovation process. **Design** can be done **for users, with users** or **by users** (Kaulio, cited in Schuurman & De Marez 2009)**.**

In an Architecture Living Lab, user involvement can range, as in any other Living Lab, from **user observation, user participation and user co-creation up to user-driven innovation (**Westerlund et al. 2011).

Physical versus virtual Living Labs

Architecture Living Labs **generally consist of real buildings**, prototype houses, existing buildings, or laboratories, which re-create a real-life environment. The physical livability of innovations at a 1:1 scale seems to be the essential characteristic of this kind of Living Labs.

Nevertheless many housing and lifestyle related innovations are based on ICT solutions, which means that they can be tested and evaluated by users only in a **virtual environment**.

Virtual reality is another option which lets users test and co-create solutions within a "similar to real-life" virtual experience and environment. User-driven and user-created "Wikis" for housing solutions based on self-construction, with free construction plans for download, and users sharing their experiences, are another example.

Finally all ICT related innovations like social platforms for more sustainable consumption, energy control in the home, or user interfaces of house management systems can be tested virtually.

It seems even possible that, similar to other sectors like the automobile or aircraft sector, the traditional "experience home" as **real prototype environment** will be accompanied increasingly by **virtual built environments** which allow simulation of user behavior and user-building or user-technology interaction in order to obtain realistic performance data as well as to collect user feedback based on virtual reality living experiences.

A critical view on the role of the users

"Users as free resource" critiques (Dutilleul et al. 2010) are generally not applicable in Architecture Living Labs, as users decide voluntarily to participate in the assessments within their home environments regarding for example new technology, a product or service, or their habits and lifestyles. Users as temporary occupants of a prototype house might not be experts in innovation processes, but their feedback, insight and personal experiences, correctly collected and interpreted, are valuable contributions for designers, researchers and developers. Critically, the limited number of user experiences which can be collected in a given time may be seen as a limitation of the Living Lab approach which can create doubts regarding the valid generalization of outcomes.

3.3.4 Open Innovation in Architecture Living Labs

The **construction sector** in Europe is traditionally a conservative field of activity, although there are important specific country differences, due to different models and dynamics in national housing markets. The Spanish Building Sector for instance has a historical **deficit in innovation**, and is traditionally based on decentralized, small-scale construction companies, and especially before 2008, had little or no innovation potential.

As an important driver of the Spanish economy, the building sector in Spain is a **significant source of national emissions**, making Spain's transition to a low carbon economy urgently necessary through a reconfiguration of this sector (Cuchí & Sweatman 2011).

Since the early 1990's the sector had little motivation for innovation from a technological point of view as "business as usual" worked well in a situation of an increasing (and artificial) boom. This reluctance could be noticed during the introduction of European **Energy Performance of Buildings Directive (EPBD) in 2002** (Directive 2002/91/EC) and in the application of the resulting Technical Building Codes, with the building industry as well as architects little prepared to meet the new standards of planning and execution as well as from the point of view of products and systems.

A recast of the Directive in 2010 (**Directive 2010/31/EU**)[34] requires all new public buildings now to have a **"nearly zero-energy" standard** by the end of 2018, as well as all new private sector buildings after 2020. In order to introduce the corresponding **necessary innovations**, the construction sector depends on generating and integrating innovation through collaborations with external agents like **companies, research centers, technology platforms or universities**.

In this context **Architecture Living Labs**, in the physical form of **prototype buildings,** seem to be projects which could generate **Open Innovation activities** among different stakeholders, benefitting from synergies among partners within a **structured collaboration process**. That way innovation in the building sector could be encouraged in order to attend to the political and social demands for more **resource efficient, sustainable and affordable housing** options.

Nevertheless, as in any multi stakeholder process, issues regarding **Intellectual property rights** and other **conflicts of interest** can arise among participants.

3.3.5 Real-life environments of Architecture Living Labs

Real-life environments allow testing **user acceptance**, involve users in **co-design** processes and observe **context related behavior** of users related to innovations. (Mulder et al. 2008)

Adapted from the general definition of **Test and Experimentation Platforms (TEP's)** by Ballon et al. (2005), the following concepts for TEP's in the field of Architecture can be described:

- **Prototyping platforms:** *Design and development facilities,* e.g. company or HEI campus workshop facilities for construction of 1:1 prototypes of components, systems or buildings.

[34] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

- **Test beds:** S*tandardized laboratory environments,* e.g. material laboratories with testing equipment for evaluation of properties of materials, building components or technologies.
- **Field trials:** *Tests of technical and other aspects in a limited, but real-life environment*, e.g. testing of components, like an energy monitoring system or an innovative façade system, within a companies' or universities' own buildings, as controlled but real-life contexts.
- **Living Labs:** *Experimentation environments in real life context with users considered as 'co-producers',* e.g. prototype solar houses occupied, tested and evaluated by users in order to improve collective solutions from product or system level up to building concept level.
- **Market pilots:** *Pilot projects with end users testing in real life contexts,* e.g. of almost market-ready technologies, products or services tested in a considerable number of private households to obtain marketing data or for final adjustments before market launch.
- **Social pilots:** *Pilot projects intended to result in societal innovation,* e.g. the introduction of an innovative type of neighborhood facility in order to generate new social dynamics and innovations, i.e. for sharing community resources or creating collaborative community service models.

Only Field trials, Living Labs, Market Pilots and Social Pilots are clearly situated in real-life contexts, although **limits between controlled environments and real-life setting can be similar**, e.g. in the case of a prototype solar house being tested under real conditions of use, but within the controlled environment of a university campus.

In the field of Architecture a clear differentiation between Field trials, Living Labs and Test beds might be difficult, as they have many **common characteristics** and are all based on experimental prototyping and evaluation of concepts, products, services or technologies related to buildings.

3.3.6 Differentiation criteria for Architecture Living Labs

Architecture Living Labs emerge where a **Living Lab approach is implemented within the context of buildings** (e.g. existing buildings, homes of people, but also a housing complex or a city quarter) or where **Prototype Architecture or Architecture Laboratories are opened up to the users**, involving them in testing and innovation activities within a societal context (prototype buildings for real clients and users) or research context (prototypes or laboratories simulating real-life contexts).

Fig. 3.5 shows how Architecture Laboratories for disciplinary research and innovation and Prototype Architecture as real-life projects are complemented through the typology of Living Labs in Architecture, which focus on holistic research and innovation in real-life settings.

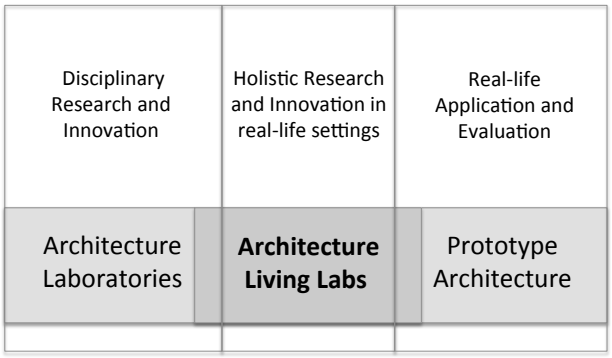


Figure 3.5 Position of Architecture Living Labs regarding other forms of experimental research in architecture

Architecture Living Labs have their own characteristics, following the general conceptual framework of Living Labs, although there are certain **communalities** with Architecture Laboratories and Prototype Architecture for example regarding research approach or setting, and limits between categories are often vague (see chapter 4 – case studies).

Types of Living Labs

The general differentiation of Living Labs initiatives (see chapter 3.2.6) in **physical places, organizations** and **networks for innovation** as proposed by Magdala & Pedruzzi (2013) can be considered valid also for Architecture Living Labs**.**

Schuurman et al. (2013) differentiates ***Living Labs as extensions to test beds*** and ***Living Labs that support context research and co-creation*** which are both focused on innovation through user involvement, from ***"American-style" Living Labs*** and ***Living Labs focused on knowledge exchange*** which are considered to be focused on exploration and not on co-creation.

In the **field of Architecture**, and taking as an example a **prototype home**, this could mean the following differentiation of the project as a Living Lab according to its focus:

- A prototype home tested under real-life and context related conditions with real occupants for a certain period **(Living Lab as extended test)**
- A prototype home used as environment to carry out context related co-creation activities with users and other stakeholders **(Living Lab as supporting infrastructure)**

Both forms of Living Labs are understood as innovation platforms for user co-creation.

Alternately according to the differentiation of Schuurman et al. (2013), a Living Lab can be focused on exploration and not on co-creation, resulting in the following definitions:

- A prototype home as show room and exhibition of technology and innovations **(Living Lab as showroom or *"American-style"* Living Lab)**
- A Living Lab as place to explore and learn **(Living Lab for knowledge exchange)**

This classification can serve as a first approach to distinguish diverse characters of Living Labs in Architecture. Nevertheless, reviewing 20 selected case studies of Living Lab like projects in the field of Architecture (see chapter 4.3) descriptions such as **applied research center, showcase home, research laboratory, demonstration building, experimental platform, community lab, prototype home, observational research facility** could be found, reflecting the diversity of approaches as well as a lack of clear categories in order to describe a movement with an emerging conceptual framework which is still under development.

Functional Categories of Living Labs

The establishment of 5 functional categories for Living Labs, namely **Innovation system, in vivo monitoring, approach for user involvement, organization and movement** according to Ditilleul et al. (2010) maintain their validity within the specific focus on Architecture Living Labs. (See chapter 3.2.6)

Drivers of Architecture Living Labs

Drivers of Architecture Living Labs can be as diverse as in any other Living Lab initiative. Based on the differentiation proposed by Nyström et al. (2012) the following 4 categories can be applied to Living Labs in Architecture:

Utilizer-driven living labs: Drivers are mainly ***companies*** *that launch and promote living labs to develop their businesses*, e.g. a building company develops a sustainable housing concept and needs to get user feedback from users about user acceptance of certain applied solutions, or feedback about usability and quality of the product as well a market viability from the users' point of view, in order to apply changes in the product or develop a specific marketing strategy.

Enabler-driven living labs: Drivers are mainly ***public-sector actors, non-governmental organizations, and financiers, such as towns, municipalities, or area-development organizations****.* Projects might focus on the establishment of a platform through a public sector initiative, which brings together local actors for societal improvements e.g. in the field of sustainable housing in order to generate knowledge, create synergies, and strengthen the local community, for example as support to a local initiative for energy refurbishment of the existing building stock.

Provider-driven living labs: This type of living lab is generally *launched as a result of actions by various* ***developer organizations such as educational institutes, universities, or consultants****.*
The goal of an initiative like that in the field of Architecture could be the creation of an open-innovation network between industry, research centers and university in order to develop new approaches to sustainable building solutions, with all participants benefiting from the generated knowledge and information.

User-driven living labs: These kinds of living labs are *established by* ***user communities*** *and focus on solving users' everyday-life problems*. In the field of Architecture this could refer to a supporting infrastructure for participatory processes, e.g. neighborhood initiatives regarding public space or community buildings, or co-creation of solutions for community problems through social innovations.

Although this differentiation of drivers of Living Labs is widely recognized and cited in the literature, some initiatives might be based on hybrid versions of these 4 categories.

The size of Architecture Living Labs

Beyond the definition of size according to Veeckman et al. (2013) based on the **number of users involved** in living lab initiative, in the field of Architecture, Living Labs typically consist of **different types of infrastructures** or supporting environments, which by themselves define the size of each project. This (physical) size can range from laboratories, pilot buildings, building complexes and whole university campus areas up to city quarters, cities or even regions.

In the following, a distinction into 3 main categories is proposed:

Small scale Living Labs: Generally more laboratory like places, where users can be researchers and can co-create innovations. A typical example can be a product development oriented living lab on lighting or ICT in homes, with the size of a room or a small building. All prototype solar homes, from the **MIT solar houses** of the 1930's and 40's (case studies H03, H06, H08) to **Solar Decathlon prototype houses** of today (case studies H25, R09-R17) could be considered small-scale Living Labs, if user involvement took place for evaluation and improvement under real conditions of use.

Medium scale Living Labs: As medium scale Living Labs could be considered e.g. **housing developments** with several units to control or monitor and evaluate for further development of concepts and innovations. The active monitoring and feedback of the first "**Passivhaus" development at Darmstadt Kranichstein** (case study H19) can be considered as this scale. Ten row house units have been monitored with their occupants giving feedback about energy consumption, comfort and usability of this new housing concept. User co-creation has been limited, but data has been evaluated for knowledge generation about the energy consumption of this type of buildings under real conditions.

Large scale Living Labs: Whole university campus areas or city quarters can be considered large scale Living Labs if applying corresponding methodologies at that scale. **University living lab projects** for examples can include the **whole campus, from buildings over green spaces up to mobility and infrastructure** with the **academic community as users**. With growing complexity and size, maybe several sub-projects form part of an overall "Campus living lab strategy". On city level, a city development area or city quarter can be a Living Lab, e.g. the **Vauban Quarter at Friburg, Germany,** (case study H22) an ecological city development with a participatory user-driven approach to innovative forms of living from a holistic lifestyle perspective. Vauban can be considered one of the early **urban living labs** for innovation in sustainability: a holistic, participatory approach for the design of whole new, green living quarter for more than 10.000 inhabitants.
The term living lab has not been applied in the context of this project, due to the novelty of the term in the end 90's. Nevertheless, the applied methodologies of user participation, co-creation, pluridisciplinarity, monitoring, evaluation and optimization within a real world environment in constant growth, reflect deeply what today can be labeled as a living lab approach.

A **"city living lab",** like e.g. City Lab Cornella[35], might also be defined as an infrastructure with activates the surrounding city quarter as living lab, not only referring to its built environment, but influencing its socio-economic mechanisms, introducing and implementing new strategies and tools for example in citizen participation, cohesion and inclusion, in order to create social value for society.

Very large scale Living Labs: Cities or regions could be considered very large scale Living Labs, if considering their built environment and inhabitants as supporting ecosystem for the application of Living Lab methodologies.

The Lifespan of Living Labs

The Lifespan of Architecture Living Labs depends on many factors and circumstances and generally varies **between several months and several years**.
The use of prototype houses as Living Labs, e.g. for technological evaluation under real conditions of use, might have generally a duration of 1-2 years.
This has been the case of most MIT Solar houses (case studies H03, H06, H08) or the **Freiburg Solar house by Fraunhofer ISE (case study H20)**. The user-centered, experimental living lab activity often terminates after that time as technological solutions have lost novelty or sufficient outcomes have been generated. As Living Lab projects are time and resource consuming initiatives, this period seems to be reasonable.
In the case of the Freiburg Solar house (case study H20) after 1-2 years technology has been updated (from hydrogen to battery storage) and the experiment has been repeated under real conditions of house occupation. Later on the project has been converted into a testbed for energy technologies in buildings, losing to a certain degree its characters as a Living Lab.[36]

Other examples linked to **Living Labs generated within HEIs for the Solar Decathlon Competition** (case studies R09-R17) show a constant but only limited use after an initial short period of intense activities. There may be many reasons for this:

- Lack of a consistent program over time, which allows maintaining only a certain level of activity.
- Lack of academic continuity of responsible personnel, leading to a lack of leadership in the project.
- Lack of attention and support from industry, public administration and press, after a first period of novelty or a specific event (i.e. Solar Decathlon Competition).
- New projects, which draw more attention to stakeholders and improve existing concepts, leaving existing ones obsolete.

City-size Living Lab initiatives like e.g. Vauban have a history of more than 15 years in continuous development through user participation, although the active user involvement in innovation decreased after the initial, constituting years and has given place to participatory community actions.

[35] http://citilab.eu/es
[36] http://www.deutsches-museum.de/fileadmin/Content/040_BN/PDFs/Prismentexte/Das_energieautarke_Solarhaus.pdf

Living Lab outcomes

Generated outcomes of Architecture Living Labs can be innovations based on user involvement in fields like **sustainable building concepts, energy efficiency, sustainable lifestyle, sustainable consumption, social innovation or behavior change of inhabitants** among others.

As in other types of Living Labs valuable insights can be generated on a **socio-economic** level (societal, environmental, health and energy cost/value aspects) or **socio-ergonomic** level (user friendliness), and on a **socio-cognitive** (intuitive) level together with insights about the acceptance and adoptability of innovations (Pallot et al. 2010).

3.3.7 Holistic evaluation of the Architecture Living Lab approach

Regarding the holistic evaluation of Architecture Living Labs, no differences from the general evaluation of Living Labs (chapter 3.2.7) can be stated referring to strengths, weaknesses, threats and opportunities of the approach.

A special strength of Architecture Living Labs is their **immediate relation to the daily life of people** regarding living and working, with a focus on housing and lifestyle. This opens important opportunities to innovate with users in sustainability related fields like **technological innovation regarding the home, sustainable consumption and lifestyle or behavior change models.**

Architecture Living Labs can range from a small scale knowledge dissemination and experience homes, up to a city platform for social innovation regarding sustainability, or the city itself with its buildings and inhabitants as supporting ecosystem for user-centered innovation in real-life environments.

3.3.8 Summary and conclusions

A **specific interpretation** of the generic concept of Living Labs (see chapter 3.2) has been offered for **Living Labs in Architecture.**

Architecture Living Labs are settled at the **intersection of Living Labs** on one side **and Prototype Architecture and Architecture Laboratories** on the other. They emerge when a **Living Lab approach is implemented within an architectural context**, or when **Prototype Architecture or Architecture Laboratories are opened up to users**, involving them in testing, evaluation and innovation activities within a societal or research context.

Physically they can consist of **prototype apartments and houses, or existing buildings and homes,** and accepting the limitations regarding a real-life context in **laboratories or showrooms, which simulate real-life environments** e.g. office space, or parts of a home.

Sectors of application are, for example, areas related to sustainable building concepts, energy efficiency, sustainable lifestyle, sustainable consumption, social innovations or behavior change, generating innovations regarding **concepts, technologies, products, materials, services or behavior changes models** which could help to reduce environmental impacts.

A **multidisciplinary approach** to innovation in the field of Architecture includes disciplines like **sociology, psychology, biology, engineering disciplines, environmental sciences, physics** as well as **design, architecture** and all related **creative disciplines.**

Users can be activated as **drivers of change** towards **low impact lifestyles** through collaboration in technology development and adoption but also through change of human habits and behaviors. Beside the **measurement of user behavior, design** in and around Architecture and specifically the home can be done **for users, with users** or **by users** (Kaulio, cited in Schuurman & De Marez 2009)**.**

ICT technologies and **virtual reality** options for representation and evaluation of building solutions will open up Architecture Living Labs increasingly towards **virtual environments**.

Open innovation among **companies, research centers, technology platforms or universities** can be considered necessary and highly beneficial for the European and specifically the Spanish building sector in order to generate the necessary innovations e.g. in the field of **nearly zero-energy buildings** or **resource efficient, sustainable and affordable housing** options in the near future.

Architecture Living Labs are a specific form of **Test and Experimentation Platforms (TEP's),** which compete with other TEPs like Prototyping platforms, Test beds, Field trials, Market pilots and Social pilots.

Architecture Living Labs also follow the generic differentiation of Living Labs as **physical places, organizations** and **networks for innovation (**Magdala & Pedruzzi 2013) with a specific differentiation proposed by Schuurman et al. (2013) in **Living Labs as extended testbed, as supporting infrastructure, as showroom** or **for knowledge exchange.** Nevertheless denominations like **applied research center, showcase home, research laboratory, demonstration building, experimental platform, community lab, prototype home** or **observational research facility** can be found in literature, reflecting the diversity of concepts and the lack of a clear classification system.

The differentiation between **drivers** in **utilizers, enablers, providers and users** proposed by Nyström et al. (2012) appears to be applicable for Architecture Living Labs, corresponding to different types of Living Lab approaches with differences in objectives, stakeholder mix, openness and lifespan.

The **size of Architecture Living Labs** shows to be a valid criterion for differentiation, as infrastructures or supporting environments do vary in size according to each type of initiative. A differentiation is proposed into **small scale** (e.g. laboratory-like places, prototype houses), **medium scale** (e.g. housing developments) and **large scale Architecture Living Labs** (e.g. university campus areas, city quarters) and **very large scale Architecture Living Labs** (e.g. cities or regions).

Lifespan of Architecture Living Labs might vary **from several month to several years** depending on the type and size of each initiative and its specific objectives, e.g. the evaluation of a new housing concept could take 1-2 years of assessment under real conditions of use.

Outcomes of Architecture Living Labs can be generated in areas like **sustainable building concepts, energy efficiency, sustainable lifestyle, and sustainable consumption or behavior change models** contributing to **technological or social innovations** in those fields.

3.4 Conclusions

It can be stated that Architecture Living Labs are a specific form of the general Living Lab approach discussed and defined in literature, centered on the **area of the built environment**, with a specific focus on residential buildings like prototype homes and solar houses.

Many fields of knowledge related to **sustainability**, like energy efficiency, sustainable lifestyle, and in general all **technological or social innovations** related to our living environments, can be researched and developed in Architecture Living Labs through an open and co-creative approach to innovation together with users, benefitting from a real-life context.

Limits between areas of application of Living Labs are increasingly mobile. Architecture Living Labs have been in the origins of the concept since the late 1990's, with an important series of historical "Living Lab-like approaches" during the 20th century, like prototype solar houses or research laboratories with user occupancy and evaluation. (See chapter 4.2)

Living Labs in the ICT sector have been the first broadly implemented initiatives to be officially developed under this concept of Living Labs, and theoretical frameworks mostly refer to this sector. This justifies the present proposal for a more **specific conceptual framework for Architecture Living Labs**.

Nevertheless, limits are becoming less acute over time, as **ICT technologies are increasingly forming part of our built environment, our homes and our everyday lives** in multiple ways, as in the fields of communication, working environments at home, control of building functions and interaction with the user, energy and comfort related control, management and communication, Internet of Things, as well as social innovations and networks of all kind.

The complexity of solutions and interactions among all physical and virtual elements of our built environment will increase over time, leading to **fully connected and controlled environments**. Living Labs can make important contributions to the management of the corresponding **systemic innovation processes** on methodological, infrastructure and network levels.

4 LIVING LABS IN ARCHITECTURE – HISTORICAL AND RECENT CASE STUDIES

This chapter offers a review of historical case studies of architecture laboratories and prototypes, introducing the historical development from early prototypes of solar architecture toward the holistic Living Lab-like sustainable architecture of today. 25 historical case studies (H01-H25) of solar architecture prototypes and 20 selected case studies (R01-R20) of recent Sustainable Architecture Living Labs are described and analyzed in detail.

4.1 Introduction

The conceptual framework of Living Labs has been described in chapter 3 in order to understand definitions, methodologies and the state of the art of this relatively new approach to innovation through participation and co-creation. The specific living lab approach in the field of architecture and lifestyle has been highlighted in this context and a theoretical framework has been proposed. Finally the relation and possible synergies between Living Labs and ESD related competences, pedagogical strategies and methods have been analyzed in order to highlight the potential role of Architecture Living Labs for ESD in higher education.

In order to further analyze the relationship between research and innovation in architecture, the specific Living Lab approach to innovation, and the resulting potential of Architecture Living Labs for teaching and learning as well as research and innovation in the field of sustainability, this chapter offers an introduction into the history of sustainability-related prototype architecture. It shows its step-by-step transformation from built laboratories into so-called Living Labs in Architecture through the detailed description, analysis and discussion of selected historical and recent case studies.

Chapter 4.2 reviews 25 historical architecture laboratories and prototype solar houses from the 20th century explaining the characteristics and evolution of these specific kinds of innovation projects mostly linked to research and education activities at universities. It gives an overview of the technological innovations and the developments in politics, regulations and society which influenced the development of different types of laboratories and prototype projects during the 20th and beginning of the 21st century in order to show the specific interdependence of these developments, resulting ultimately in the appearance of the Living Lab approach in architecture.

Chapter 4.3 reviews 20 selected recent Architecture Living Labs, which are currently operative, and analyses their characteristics, the specific applied methodologies, the outcomes reached, and all available project specific data, which contributes to identifying and describing their specific characters.

Chapter 4.4 offers general conclusions about the analysis of the selected historical and recent case studies of Architecture Living Labs in order to highlight the evolutionary process of transformation from specific prototype laboratories to holistic Living Labs in Architecture.

4.2 From evaluation of prototype solar houses to Living Labs in Architecture

This chapter offers a basic introduction into the history of sustainability-related prototype architecture and its development towards so-called Living Labs in Architecture.

A selection of 25 historical experimental buildings has been made, showing the development of laboratory and experimental building evaluation throughout this period, focusing on prototypes and experiments of the 20th and beginning of the 21st century. (See Appendix 1: Project data sheets of 25 historical Living Labs like laboratories and prototype houses)

Due to the limitation of this work this review can only contain a limited number of examples in order to better understand the historical context of today's Living Lab projects and the long history of prototype architecture, which influences developments in this field right up to the present day.

Selection of projects

The following projects have been selected for their focus on sustainability, clearly related to solar energy use and storage since the early 20th century, but also for including an experimental development and evaluation approaches towards new materials and technologies, new spatial concepts for an optimization of energy performance and construction innovations. All projects aim to analyze, evaluate, measure and further develop the applied innovations of their time, and many of the results have contributed to today's building technologies, installations and standards.

Emphasis is given to projects, which formed part of research programs related to sustainability, which basically refers to efficient construction systems, energy saving materials and systems, as well as the use of renewable energy technologies. The testing and evaluation under real conditions of use has been another selection criterion.

The following 25 examples of prototype architecture of the 20th and early 21st century will therefore be analyzed under the focus of their relevance as predecessors of today's *Living Lab* concepts in architecture, besides their general significance and contribution to development and innovation in the fields of sustainable housing and life style.

Historical approach to prototype buildings

In the late 19th century, with coal as the main energy resource, energy consumption for both industrial production and also for comfort in buildings had an immediate impact on the health and wellbeing of the population. Unhealthy living conditions in dense, contaminated,

industrialized cities such as London or Berlin at the end of the 19th century led to the first reflections about how a healthy living environment should be, especially for working class people. (Butti & Perlin, 1980, p.160ff)

After World War I, social housing movements like those in Berlin and Vienna attended to these issues. Ambitious housing programs during the 1920's developed housing blocks for working class people as well as "Siedlungen", new housing developments outside the cities, attending to the necessities of living space, fresh air, sun, comfort, services and social community. It is important to remember that one of the most important reasons for this special interest in solar architecture was the limitation of economic and energetic resources during this decade.

At the same time building materials were developed for more economic and energy efficient buildings. The modern movement developed not only efficient building structures and housing typologies, but also innovated in corresponding systems and materials for heating, services, insulation, and comfort in general.

4.2.1 Prototype solar architecture of the 1920/30's

Expositions like "Haus am Horn" by the Bauhaus in 1923, the "Weissenhofsiedlung" at Stuttgart in 1927 or the "Das Wachsende Haus" competition in Berlin in 1932 started on larger scale research activities in building materials, systems and typologies as well as energy efficiency and the use of solar energy in buildings exhibiting the results directly to the population.

The development of new "*Siedlungen*" (housing communities, mainly based on social housing) started with a new approach to housing, facilitating access to "light, air and green" for all, especially the lower income population, fostering self-sufficiency through vegetable gardens and physical and psychological well-being for its inhabitants.

Martin Wagner was one of the important architects and urbanists in the post World War I Berlin[37], and as chief city planer organized the International working group **"The Growing House"** in 1931 and a corresponding Building Exhibition in 1932 under the same name. The concept behind this was the idea that buildings should be prefabricated and "growing" according the necessities and economic possibilities of the inhabitants. His **"Growing House" prototype** (case study H01) is an example of an innovative floor plan together with passive solar features through thermal buffer spaces, built through a second skin of the house and made of an inclined glassed wall. The whole organization of the building follows the structure of an onion, in order to keep warmth inside during winter and use passive energy gains efficiently, as well as creating a green house space for vegetable growing integrated into the overall house concept. The house was presented at the exhibition mentioned, but no evaluation is recorded through monitoring or any evaluation under real conditions of use.

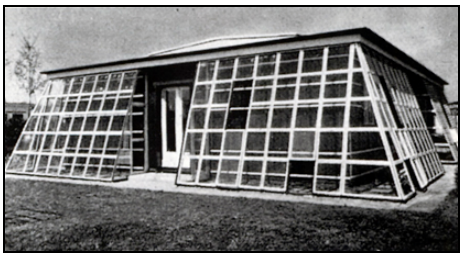


Figure 4.1 The Growing House south façade

From the 1930's onwards, based on European post World War I experiences in solar housing and the mentioned "Siedlungen" based on the modern movement, a new consciousness about the

[37] https://en.wikipedia.org/wiki/Martin_Wagner_(architect)

right orientation of buildings for passive solar energy use and better comfort arose in the United States. (Butti & Perlin, 1980, p.160ff)

George Fred Keck was one of the pioneers doing experimental solar architecture by introducing south glazing into residential buildings for passive solar gains in winter, protecting these surfaces through roof overhangs against excessive solar radiation in summer.

His **Home of Tomorrow** house (case study H02), was built for the Homes of Tomorrow Exhibition, which was part of the 1933 Chicago World's Fair. It[38] was based on a dodecagonal design using a prefabricated aluminum structure. Plate glass walls created highly glazed spaces, allowing the use of passive solar energy in the building. (Ken Butti, John Perlin, 1980, p.183f)

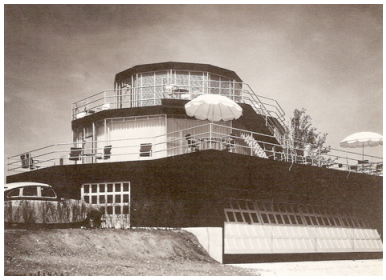


Figure 4.2 Glass House of Tomorrow

Nevertheless it was not Keck's intention to build a solar home, as this concept was unknown at that time, but the experience of passive solar gains in this glass house led him to discover the phenomenon of solar architecture. (Anthony Denzer, 2013, p.36)

The so-called first **"Solar Home",** built by Keck in 1940, was his **Howard Sloan House** in Glenview, Illinois, (case study H04), a building with a totally glazed south facade (Ken Butti, John Perlin, 1980, p.184)



Figure 4.3 Howard Sloan House, Glenview

Keck first assessed thermal comfort through visits to his houses, interviews with the inhabitants and taking notes about comfort conditions at each time of the year, with the aim of understanding better the effect of green houses, glass façades and other features which can contribute to the efficient use of passive solar gains, but which on the other hand can cause severe problems of heat loss in winter or overheating in summer. (Ken Butti, John Perlin, 1980, p.183f)

Continuing, one can state that the following premises and research fields have decisively driven the **prototype solar architecture of the 1920's and 1930's**:

- Housing concept innovations regarding distribution and building structure, searching for economic prefabricated buildings.
- Introduction of passive energy features like passive solar gains, sun protection or buffer spaces, quantifying their effects for the first time.
- First building evaluations through direct user surveys and control of specific data like room temperature and overall yearly energy consumption for heating under real conditions of use.

[38] https://en.wikipedia.org/wiki/House_of_Tomorrow_(Indiana)

4.2.2 Prototype solar architecture of the 1940's

At the same time, in 1939, an ambitious research program started at the **Massachusetts Institute of Technology (MIT)** in Cambridge, USA, which throughout the 1940's generated valuable knowledge through several prototype houses researching the active use of solar energy in buildings.



Figure 4.4 MIT Solar House I

The first prototype, the **MIT Solar House I** (case study H03), focused its research on solar water collectors for domestic heating systems. A laboratory building was constructed and 38m2 of collectors were installed over a 30º-pitched roof with south orientation. A 66.000 liter hot water storage tank was installed in the basement, to feed a centralized air heating system with fans. Good thermal performance was successfully proved, but economically the system was not viable for the market. No occupation of the house with real-life users took place, so that this first solar house had more the character of a traditional laboratory for the evaluation of technology concepts. (Ken Butti, John Perlin, 1980, p.200f)

Another important experiment was carried out the MIT in 1947. An air heating system through a water wall system was examined for efficiency. The laboratory building, **MIT Solar House II** (case study H06)**,** consisted of 7 small spaces, with variations of the system installed, so that comparative measurements could be done. Despite technical problems with elevated energy losses of the system through the glazed surfaces, 38 to 48% of heating demand could be provided by solar energy. (Ken Butti, John Perlin, 1980, p.206ff)



Figure 4.5 MIT Solar House II

The **MIT Solar House III** (case study H08), a further development of the second, operated between 1949 and 1953 successfully with solar heating based on solar water collectors and a 4.450 liter hot water storage tank. Special attention was given to good passive solar design through large south glazing. The prototype solar house was **inhabited by a former MIT student** and his family, so that the building could be **tested under real conditions of use**. 44% of the heating demand could be recovered by the optimized active solar system and only an 11% of the demand had to be contributed by an electric back-up system. This house was fully operative over 4 years with users contributing to the experimental evaluation through the regular occupation of .the house. (Ken Butti, John Perlin, 1980, p.208ff)



Figure 4.6 MIT Solar House III

The **Dover house of 1949** (case study H07) experimented with an 'only-solar' concept, based on the capacity of the heat storage of 13 tons of *Glauber* salt as phase change material with a melting point of 33º C in combination with a vertical south air collector façade of around 80 m2.
The **house was occupied** and worked satisfactorily for 2 years before technical problems led to the installation of an electrical heating system and finally oil heating by its owner. The oversized installation and the lack of deeper evaluation created serious doubts about the efficiency of this system. (Ken Butti, John Perlin, 1980, p.211ff)

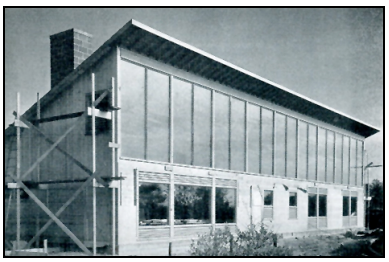


Figure 4.7 House for Amelia Peabody at Dover

Another important example of prototype architecture of the 1940's is **Frank Lloyd Wrights' Solar Hemicycle (Jacobs II House), built in 1948** (case study H05) with a sophisticated passive solar design which allowed direct solar gains through the semicircle southwest façade with shading by an effective solar control through the cantilever, and the use of masonry walls as thermal mass and an earth bank as natural thermal insulation of the north façade. The house was regularly in use, and according to its original owners, Herbert and Katherine Jacobs, comfort was extraordinary through the passive solar gains in winter. Nevertheless due to lower construction and insulation standards, the house had to undergo fundamental refurbishment in the 1980's in order to improve the interior comfort conditions. (Anthony Denzer, 2013, p.59ff)

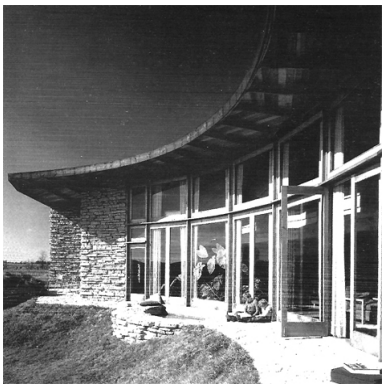


Figure 4.8 Jacobs House II, Middleton

Summarizing, it can be stated that the following premises and research fields have decisively driven the **prototype solar architecture of the 1940's** selected here:

- Innovative floor plans and the search for the right building orientation for maximizing passive solar gains.
- Research on active solar systems for heating together with thermal storage researching "only-solar" solutions.
- Evaluation through detailed measurements of comfort, system performance and overall energy balance of solar houses, including user behavior under real conditions of use.

Nevertheless many of the projects suffered from technical problems of the developed systems and a **lack of detailed monitoring possibilities** which gave place to estimation and intuition in the concept design, rather than consolidating the market-readiness and real-world tested solutions of solar houses. Together with other circumstances, due to the politics in Germany and the war related economic restrictions in the USA, this did not allow for the maturity and large-scale development of solar houses.

4.2.3 Prototype solar architecture of the 1950/60's

The **MIT Solar House IV** (case study H11) was built as a single-family home at Lexington, MA, in 1958, using solar water collectors again for heating, with an overall solar capacity of 50% of the heating demand. Detailed monitoring and economic calculations formed part of the research process, resulting in the need for a cost reduction of 80% in order for the solar heating system to become competitive in the market, due to the low prices of fossil fuels at that time. The house, as a newly built project, was **occupied with a family as regular residents**, in order to allow **research under real conditions of use**. (Ken Butti, John Perlin, 1980, p.216f)



Figure 4.9 MIT SOLAR HOUSE IV

Despite showing technical viability, the solar technologies could not finally compete economically against systems based on cheap fossil fuels, leading to the **termination of the MIT solar research program** at the end of the 1950's. (Ken Butti, John Perlin, 1980, p.216)

Other representative experimental solar buildings of the 1950's are the **Solar House at Rickmansworth, UK (1954)**, by Ed Curtis (case study H09), and the **Löf House in Cherry Hill, Colorado (1957**) by George Löf and James Hunter (case study H10).

In the **1967** Fèlix Trombe and Jaques Michel built a **Solar House in Odeillo**, France (case study H12), using an innovative passive heating system, the so-called **Trombe-Michel wall**. Based on an opaque absorber wall with a high heat capacity, an air gap and an exterior layer of glass, the system worked like a solar collector and was able to absorb and store heat during the day. At night time it was possible to release heat through circulating airflows or direct heat emission towards the interior of the house.

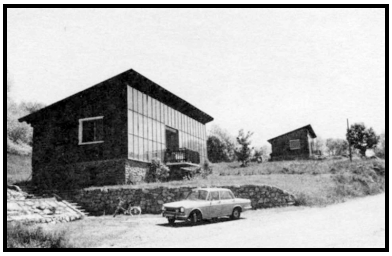


Figure 4.10 House at Odeillo

To summarize, it can be stated that the following premises and research fields have decisively driven the **prototype solar architecture of the 1950/60's:**

- Exploration of increasingly complex thermal energy concepts with sophisticated storage systems.
- Optimization of passive solar design and innovation or improvements of existing solutions, i.e. the Trombe-Michel wall.
- Holistic evaluation of comfort, system performance and overall energy balance of solar houses, through increasingly sophisticated laboratory measurement equipment, including economic calculations about market competitiveness.

Nevertheless these projects and concepts and their corresponding research programs, industrial developments and market deployment of products and systems, suffered heavily with cheap oil prices and a society unconcerned about the environmental impact of fossil fuels or energy security. Together with the rapidly developing post-war economy driving higher living standards

through the use of air-conditioning systems and the increasing number of in-house electrical appliances, solar architecture and technologies lost their attraction.

4.2.4 Prototype solar architecture of the 1970/80's

In the early 1970's **Steve Baer** started utilizing solar energy to heat buildings directly. He tried to store the energy obtained by solar passive gains in devices like walls made by black painted metal drums full of water behind a glass sheet or rock beds buried in the ground.

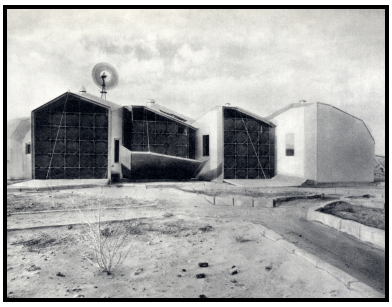


Figure 4.11 House at New Mexico

In 1971 he built his widely published own **home at Albuquerque**, **New Mexico** (case study H13), where he tried using the water walls to store passive solar gains applying a system for insulation at night using thermally insulated reflective movable panels on the façade.

> *"The drums are painted black on the sunward side and placed behind glass to increase heat absorption. Huge insulated panels are lifted up and down on winches to expose the drums to the sun in winter and heat the water. When the doors are closed at night, the heat radiates from the water in the drums and warms the rooms. In summer, the doors are closed throughout the day and may be opened at night when the temperature drops. This action keeps the water cool, so during the day, when the house gets warm inside, the cool water soaks up this heat and acts as a natural form of air conditioning."* (Domus no. 546, 1975 May, p. 20-21)

Steve Baer is an example of the **first generation of solar architects** in the United States, who were searching for low cost, alternative architecture to reach as close as possible to energy self-sufficient buildings in the 1970's. His Albuquerque house is recorded to recover 85% of its heating demand through the sun. (Idem)

This rather individual and intuitive approach to solar energy in buildings was soon strengthened through structured research programs on international level.

In 1978 the MIT Department of Architecture built another prototype at Cambridge - the **MIT SOLAR HOUSE V** (case study H14), which mainly focused on passive solar energy optimization through innovative window solutions. Another example is the **Prototype Solar House in La Plata** (case study H15), Argentina, built by Elias Rosenfeld in 1979 as a government financed research project.

These rather individual approaches got an important impulse through the start of the International Energy Agency's **IEA Heating and Cooling Program**. The IEA was established in 1974 as an autonomous agency to carry out energy cooperation among its member countries and the Commission of the European Communities.[39] Its' Solar Heating and Cooling Program was

[39] http://www.iea-shc.org/programme-description (accessed July 2015)

established in 1977, with the mission to enhance collective knowledge and the application of solar heating and cooling through international collaboration.[40]

Within the **IEA Task 13 "Advanced Solar Low Energy Buildings",** a program of 16 low energy solar houses have been built and monitored in different countries with the aim of limiting the total energy consumption for space heating, domestic hot water and electricity to only 25% compared with the typical consumption of new houses in the participating countries. (Thomsen et al. 2005)

The majority of the projects were monitored for a longer period under real conditions of use, and user feedback formed an essential part of the evaluation.

Significant examples of the solar house prototypes created are the **IEA Low Energy Houses in Kolding**, Denmark by Boje Lundgaard & Lene Tranberg, 1989, (case study H16) with the Thermal Insulation Laboratory (DTU) as research partner. The applied innovative building features are super-insulation, high performance windows, solar domestic hot water, fast responding heating, ventilation heat recovery and energy-efficient appliances and lighting.



Figure 4.12 Danish Low-Energy Row Houses

Energy performance was monitored over a period of 1 year and compared to calculated results (Hestnes et al.1997). Surprisingly the houses consumed much more energy than expected, and research on the reasons for this led to the following results:

> *"In the Danish house the high energy consumption can be attributed to three main reasons: (1) the balanced ventilation system with heat recovery in fact worked as an exhaust system as the inhabitants had stopped the part supplying air, because of draught and noise problems; (2) the solar heating for domestic hot water was not functioning for more than 3 months, when a valve was closed for repairs and was unfortunately never re-opened and (3) the indoor air temperature was about 4C above the presumed value. Beside the indoor air temperature, the large deviations are caused by defects, which are not directly linked to the actual low energy design."* (Thomsen et al. 2005)

An important part of this program has been the **collection of user feedback**, understanding the inhabitants of solar houses as important elements in the correct operation of the house, and the overall objective to reduce energy consumption. Users of the houses commented on noise and draught problems caused by the ventilation system and temporary overheating problems, and expressed the desire to receive more information about the systems and the physics of the building. (Thomsen et al. 2005)

[40] idem

Other important prototype solar houses generated through the same IEA program are the **Zero Heating Energy House in Berlin, Germany** (Research Partner: Institut für Bau-, Umwelt und Solarforschung, Fraunhofer Institut für Bauphysik, case study H17) and the **Norwegian row houses in Hamar**, **Norway**, (Research Partner: SINTEF, NTNU, Department of Building Technology, Norwegian Institute of Technology, case study H18), both built in 1989 and monitored and evaluated under real conditions of use.



Figure 4.13 German Zero Heating Energy House

In summary, it can be stated that the following premises and research fields have decisively driven the **prototype solar architecture of the 1970/80's:**

- 1970's: Low cost solar energy systems based on passive solar gains, storage and distribution with a highly experimental character and self-construction concepts.
- Social and political consciousness about the potential of solar energy and energy efficiency in buildings through oil crises of 1973 and 1979 and a growing environmental movement leading to more research and prototyping.
- End of the 1980's: Start of structured research through the International Energy Agency (IEA) - Solar Heating and Cooling Program on Low Energy Solar Buildings with an important focus on evaluation under real conditions of use, long-term monitoring, cross-cultural research at international level, and evaluation of user-building and user-technology interaction.

At the end of the 1990's, the **first holistic research and innovation projects** were organized and carried out on an international level with regard to low energy solar architecture. Projects are designed, giving importance to the **evaluation of new concepts and technologies under real conditions of use** during a longer period. The **role of the user** as an important actor regarding energy savings and overall energy consumption of a building, as well as the influence of technical systems and design decisions on space, quality and comfort are part of the research and innovation approaches in this period. Nevertheless, the user is generally not yet a driver of the process, but is observed in the interaction with his home.

4.2.5 Prototype solar architecture of the 1990's

In the 1990's research on solar energy systems and their integration in buildings had already been established as a **consolidated area of interest in major research institutes** worldwide, like the DOE's National Renewable Energy Laboratory (NREL)[41] in the United States or the **Fraunhofer Institute for Solar Energy Systems ISE in Germany**[42].

[41] http://www.nrel.gov
[42] http://www.ise.fraunhofer.de

Since the late 1980's new low energy building concepts and corresponding standards have been researched and developed with a major concentration of research activities in Germany, Austria, Switzerland and Denmark. **In 1990 the first so-called *Passivhaus* (Passive House) was built in Darmstadt Kranichstein** (case study H19) and an Institute of the same name, the *Passivhaus Institut*[43], founded in 1996, gave place to its development, promotion and implementation of the *Passivhaus* concept in Germany and abroad.



Figure 4.14 Passive house in Darmstadt

The main features of the Darmstadt *Passivhaus* are the use of direct solar gains, a high thermal insulation without thermal bridges, high airtightness, a ventilation system with heat recovery, triple pane glazing, highly insulated window frames and solar hot water through vacuum tube solar collectors. The project has been monitored under real conditions of use and showed convincing energy consumption data of less than 10 kWh/m2.

The Fraunhofer Institute for Solar Energy Systems ISE made one further step forward with its **Solar House at Freiburg**, **built in 1992** (case study H20). This project turned out to be the **first self-sufficient energy home** in Germany which was disconnected from the energy grid and exclusively powered by solar energy.[44]



Figure 4.15 Solar House Freiburg

This prototype has a semi-circlular south façade with large amounts of glazing for passive solar gains in winter, together with translucent insulation panels and walls collaborating as thermal storage device between day and night time, which complement the active solar thermal and solar photovoltaic systems and their corresponding storage facilities.

Excess solar energy generated in summer through the building's integrated solar systems is stored in the form of **hydrogen** in a tank in the garden, operating **fuel cells** to generate electricity when necessary.

The house was tested under real conditions of use as a family home until 1996, **demonstrating that it is possible to operate a single family home under the central European climate with solar energy alone**. Hydrogen technology proved to be immature for use as a home energy system, but overall performance of the building was satisfactory. This prototype has since served as a testbed for solar technological innovations and a general research test-bed for energy in buildings.[45]

[43] http://www.passiv.de
[44] http://www.deutsches-museum.de/fileadmin/Content/040_BN/PDFs/Prismentexte/Das_energieautarke_Solarhaus.pdf
[45] idem

A third interesting example of prototype solar buildings as laboratories for a new kind of housing is the **Heliotrope House**[46] at Freiburg (case study H21), built in **1994 by Rolf Disch** as the first **Plus Energy Building**, a building that produces more energy than it consumes under regular operation.



Figure 4.16 Heliotrope Solar House

The house, a single-family home with a round floor plan, is based on a **rotary structure**, which allows the house to "follow the sun" in order to optimize direct solar gains during the whole day. Furthermore, it contains a dual axis tracking PV system, a geothermal heat exchanger, a combined heat and power unit (CHP), solar thermal collectors, high thermal insulation and a grey-water recycling system.

The prototype is the architects home and private office, and is a **unique experiment** for the alternative concept of a solar house which is reported to operate satisfactorily, although it did not succeed in broader market implementation.

Summarizing, it can be stated that the following premises and research fields have decisively driven the **prototype solar architecture of the 1990's:**

- House concepts with the latest technologies and innovative materials, showing that energy self-sufficiency, and even positive energy balance is possible in buildings.
- Building optimization and system design through increasingly sophisticated simulation tools and a high level of pluridisciplinary research.
- Evaluation through sophisticated monitoring equipment and data acquisition under real conditions of use.
- Generation of new building standards and brands like *Passivhaus* and *Plus Energy House and* the first market deployment of these concepts.

In the early 1990's energy self-sufficiency seems to have been a desirable objective for solar building researchers to reach, in order to show the whole potential of energy generation, transformation, storage and management technologies under development; although conceptual **research evolved more and more towards grid connected buildings**, the understanding of self-sufficient energy buildings as singular cases when grid connection is not feasible, was gained. Significant building concepts like the *Passivhaus* and the *Plus Energy House* showed their technical viability through prototypes, and began to be recognized as building standards, and be accepted as mainstream through market deployment.

Users are an essential part of the experimental building evaluation in the 1990's in order to test prototypes under real conditions of use, and get user feedback about the **increasing amount and complexity of technical solutions** the habitants have to deal with as well as **changes in the traditional way of living,** (i.e. regarding ventilation).

[46] http://www.rolfdisch.de/index.php?p=home&pid=78&L=1#a566

4.2.6 Prototype architecture of the 2000's onwards

As opposed to single buildings, in the 2000's the focus shifted towards a holistic understanding of **communities or city quarters as ecosystems**, which allows generating synergies between the individual components on a **technical level**, i.e. through smart grids, local energy generation or system interactions between housing and mobility, using storage systems for renewable energies shared collaboratively. Local energy generation and distribution, seasonal thermal energy storage, electro mobility or renewable energy cooperatives are examples of these developments, which technically connect the individual housing units among them, or lets them interact with other components like the local energy grid, similar to a car and its electrical storage devices.

The same synergies are also found on the **social level**, i.e. through social innovations regarding food, mobility or community services and activities. Community gardening, local organized food markets, car pooling or sharing and co-housing concepts are examples of these developments.

In brief, so-called **ecological housing developments** try to create the conditions for **new low-impact lifestyles** of their inhabitants as holistically as possible. Users have to learn, understand, desire and adopt the necessary change in lifestyle, and therefore form an important part of the whole development process right from the start.

An important example is the **ecological city quarter Freiburg Vauban (Freiburg, Germany)** (case study H22), which started in the early 1990's but was only fully implemented in the late 2000's with more than 5500 inhabitants and 600 work places.[47]
The main goal of the project has been to **implement a city district in a co-operative and participatory way**, which meets ecological, social, economic and cultural requirements. It is one of the most important reference projects in Europe with regard to citizen's participation, energy, ecology, social matters and mobility.



Figure 4.17 Passive Houses Gärnter at Vauban

Houses are built with improved **low energy standard** (less than 65 kWh/m2a heating demand) and 100 units are built as "passive house" (15 kWh/m2a) or "plus energy" home (houses which produce more energy than they need).[48] Other features are:

- Highly efficient co-generation plant (CHP) connected to the district's heating grid.
- Widespread use of solar collectors and photovoltaics in the district's buildings.
- An ecological traffic/mobility concept with good public transport, a reduced number of private cars, only periphery parking space, 40% car-free households and car sharing system.
- Streets and other public spaces as playground for children and places for social interaction.
- Joint building co-operatives with high ecological awareness.
- Participation structure for social innovative ecological and social concepts.[49]

[47] http://www.vauban.de
[48] idem

A related project is the **Plus Energy House Settlement, Freiburg** (case study H23), opposite to the Vauban area, designed and built by **Rolf Disch** in **2006**, shows the viability of a mass deployment of this specific energy standard.

Another similar project, although at a reduced scale in comparisons to Vauban, is the **BedZED Housing Development**, Beddington, UK, designed by **Bill Dunster** and built in **2002** (case study H24)**.**



Figure 4.18 BedZED, housing development, London

BedZed is a **mixed-use urban development** for around 300 habitants and users, which offers space for **living and working** in sustainable **solar houses**, using passive solar and ventilation strategies together with cost efficient active technologies. On a community level, BedZED includes a biomass combined heat and power plant, an onsite sewage treatment and rainwater recycling system, and a mobility charging space for electric cars. [50]

The development shows that it is possible to create a **carbon neutral settlement** with high quality living space and shared infrastructures as well as a socially mixed community, which encourages and supports its inhabitants in the adoption of a **more sustainable lifestyle**.[51]

This new approach to **housing related to its social environmental context** with its resulting complexity, requires the **active role of users** or future inhabitants from an early stage of the project onwards. Users are not only observed subjects, but decisive actors in the design and operation of the whole community. This is in addition to their role regarding energy efficiency and the general reduction of resource consumption on an individual level, referring to not only energy, but also water, space and infrastructure.

In order to promote solar architecture, raise awareness of the potential of solar energy in society and foster related efficient, project-based teaching and research activities in higher education institutions, the **US Department of Energy (DOE)** launched the first **competition on solar housing in 2002,** called **Solar Decathlon** (case study H25).



Figure 4.19 Solar Decathlon Competition 2009, Washington

This competition has evolved since then into an on-going and expanding series of international competitions worldwide, which encourages the generation of innovation in the tradition of the historic MIT solar house program, but with even broader implications for different disciplines, companies and institutions, and an increasingly holistic approach to sustainable housing and lifestyle. More than 200 prototypes have been built since 2002.

[49] idem
[50] http://www.zedfactory.com/zed/?q=node/102
[51] idem

In conclusion, it can be stated that the following premises and research fields have decisively driven the **prototype solar architecture of the 2000's onwards:**

- Implementation of holistic House-User-Resource concepts and innovations for a more sustainable life-style within ecological community developments.
- Integration of passive and active energy features like PV, biomass, passive solar, natural ventilation and buffer spaces, under well-established energy standards like *Passive House* and *Plus Energy House,* with connection to local grids.
- Detailed monitoring and performance evaluation together with holistic environmental impact analysis at house and community levels.
- The users increasingly become actors in and even drivers of the processes related to sustainable housing and lifestyle within the context of communities.
- Research and innovation in technologies and holistic sustainable housing concept has been fostered internationally, for example through the Solar Decathlon competitions, setting higher education institutions in the center of open innovation activities towards more sustainable housing and lifestyles.

Finally, it can be stated that individual experimental prototype houses might be considered as living labs at a building scale, but the strength of projects like Vauban or Bed-ZED is their approach on a community scale, converting a whole city quarter into a **City or Community Living Lab** for the co-creation, implementation, experimentation, evaluation and constant improvement or further development of a holistically low-impact lifestyle for individuals, and also a whole community.

These developments illustrate the transition from **user-centered to user-driven and open innovation** (essential part of the living lab approach) with the participation of all implicated stakeholders and a pluridisciplinary and holistic view on sustainability, settled in the real-life environment of a city quarter.

4.2.7 Discussion

A review of 25 historical projects has been presented in order to show the gradual transformation from built laboratories towards so-called Living Labs in Architecture during the 20th and beginning of the 21s^{t} century. The review focuses on a limited number of case studies, related to so-called solar architecture and does not consider other important contributions such as those of the modern movement (Mies van der Rohe, Le Corbusier), the Brutalism of the 1950's (Alison and Peter Smithson) or the increasing implementation of ecological architecture of the end 1970's and 1980's.

Nevertheless the selected projects contribute to a holistic understanding of the development of architecture laboratories and prototypes in the 20th century related to solar energy and sustainability in general.

Drivers of innovation projects

This historical review shows that often the key moments of technological developments and socio-political or economic milestones during the 20th century led to specific prototype developments and steps forward towards i.e. a more energy-efficient architecture or the integration of solar technologies into buildings. This regularly resulted in research, development and evaluation through prototype buildings.

At different moments in time, this has been driven by social demands for housing, new building codes, new available materials and technologies (i.e. double glazing, solar technologies, and insulation materials), global energy crises, green movements, energy politics, private initiatives and scientific research results. Particularly in recent years, the capacity to understand the complex nature of sustainability in a holistic and global sense has driven and continues to drive these developments and innovations.

Towards a holistic user-building approach

The historical review above also shows that buildings are better and better understood in their complexity as being deeply related to aspects such as resource consumption, environmental impact of materials, land use, but also to lifestyle, the capacity of forming part of intelligent systems (smart grids, smart cities), mobility, self-sufficiency, health, local economies and new economic and social concepts of living like co-housing or intergenerational homes. The role of the user has gained increasing importance and its relation and interaction with technological systems and the whole building have been studied in depth, leading to so-called user-centered research and innovation.

Therefore, prototypes increasingly turned into laboratories under real world conditions, with users living inside and a holistic evaluation methodology, covering all aspects from technical and, economical to human issues which are all important for the development of an energy efficient, holistically sustainable domestic architecture, one which supports users in the adoption of a more sustainable lifestyle at the same time as it facilitates comfortable and secure spaces for diverse and changing forms of living.

In this sense the prototype houses of today have developed into more complex “living” objects, with the possibility to monitor, evaluate and improve in real-time all aspects related to energy optimization or improvement of performance for a more sustainable life style of its inhabitants. Nevertheless, historical examples show that the approach to user-centered research regarding comfort and “livability” of innovative housing under real conditions of use had already been introduced in the 1930’s through early monitoring and user inquiries.

Sensor technologies and data collection

Many architects and experts on solar energy discovered the possibilities of solar energy in buildings through field experiences or by circumstance. As mentioned in chapter 4.2.1, in the 1930’s George Fred Keck experimented with gradually growing south glazing in a series of private houses. He periodically visited the houses, documenting the energy consumption and collecting experiences of its inhabitants in order to validate his solutions, but without the possibilities of a deeper assessment through monitoring.

Nevertheless as early as 1947, MIT already had available complex data collection systems, which allowed continuous monitoring, as for example in their water wall experiments at the MIT Solar House II.

Technological development of information and communication technology (ICT) and specifically the development of wireless sensoring and data transmission technologies contributed further to the evolution from isolated data collection and evaluation to large-scale real-time data availability and building monitoring.

Nowadays the development of sensor technologies and ICT in general allow collecting data, monitoring performance and behavior as well as continuously and precisely evaluating all collected information in order to improve, change or innovate any technical or conceptual issue of an experiment or prototype. This may even influence the behavior of their inhabitants, for example in guiding them towards a more efficient technology-user interaction or a general behavior change.

Building Management Systems (BMS) or Building Automation Systems (BAS) further support todays building operations and maintenance.

From observational laboratory to Living Labs

The improved access to experimental data through monitoring devices and improved observational tools for user-centered research allows new forms of user-centered experiments, focused on user behavior not necessarily under laboratory conditions, but in real-life contexts such as homes or office buildings in regular use.

The term *Living Lab* describes these types of interactive, user-centered, real life environments, which foster innovation in the context of a pluridisciplinary research environment with the participation of a great variety of stakeholders.

Despite the fact that tools and methodologies, infrastructures as well as organizational definitions of existing Living Lab projects are diverse and nowadays cannot be grouped under a single definition, it can be stated that the experimental houses of the 20th century adopted step-by-step Living Lab characteristics. Such projects evolved towards the Living Labs of today within the field of architecture through the improvement of technological solutions for monitoring and the increasing research focus on users as well as context.

It can therefore be stated that prototype architecture today is increasingly defined through a living lab approach on a larger scale, within a real setting and specific social, economic and environmental context.

Relation to research and education

The focus of this review has been on projects linked to university and research institutes, or to projects which are highly innovative for other reasons, with specific regard to so-called solar houses. Research and innovation has often been generated within or together with higher education and research institutions (MIT, ISE, Passive House Institute).

Higher Education Institutions and specifically **Schools of Architecture** seem to get implicated again in these processes as for example through participation in the international **Solar Decathlon Competitions** with more than 200 prototype solar house built at the date of writing. This means that not only research, but also the regular education of architects focuses more and more on a holistic approach to sustainability, combining theory with building practice and prototype building, operation, monitoring and evaluation.

It is about dealing with **complexity**, but also with **uncertainty**, leaving open options for transformation, adaption at all scales (i.e. open protocols, open source, modularity) i.e. the "update" of certain technologies in different stages of the life cycle of the basic supporting structure of a building or a city quarter. So, despite technical challenges and innovations, it is about reflecting on a new way of living for society and the search for a new low-impact lifestyle, and it is about values, on both a personal and collective level.

Final considerations

Although Living Labs in Architecture might not have had that name until the definition of the term living lab in the early 2000's, in one way or another, the approach already existed in the history of prototype solar architecture in the 20th century through the following characteristics which projects integrated step by step:

- **User-centered research:** evaluation of user comfort, user-technology interaction, user inquiries, performance monitoring.
- **Innovation (with certain degrees of openness):** joint pluridisciplinary research projects at universities or private research institutes, or private architecture practices together with different experts and even the future owners and inhabitants.
- **Testing and evaluation in real-life environments:** 1:1 prototypes, occupied solar houses, regular housing developments.

This allows recent Living Lab projects in the field of Architecture to be better understood, which is the central research focus of this work and which will be analyzed and discussed in the following sections.

4.3 Review of 20 recent Living Labs in Architecture

In the following 20 examples of relevant *living lab-like* infrastructures or architecture laboratories for research and innovation linked to universities or in close contact to higher education teaching and research activities are described.
An overview is given concerning their main aspects regarding research and innovation research, applied methodologies and tools, stakeholders and user groups of the individual projects, as well as their specific approaches to sustainability.

These 20 selected projects are from here on referred to as "Living Labs", although their Living Lab characteristics still remain to be investigated later in this work and some might correspond to the diverse definitions of a Living Lab only to a certain degree. This is in order to avoid a variety of substituting terms like "living-lab like initiatives", "prototypes with living lab characteristics" or similar ones and may be justified by the inexistence of a clear definition of the term and specific criteria which would allow to differentiate clearly between *living laboratories* and those which are not "living".

All 20 Architecture Living Labs apply extensive user-centered research and innovation approaches in real-life settings or have the potential to do so. The objective is to analyze and compare on the one hand their characteristics, their applied methodologies, methods and tools as Living Labs, and on the other, their specific contribution to ESD.

Selection of projects

These projects have been found through general search in the World Wide Web on the topic "Living Lab"[52], and through the follow up of prototype solar houses developed world-wide by universities since 2002 for the international university competition Solar Decathlon (SD). Since 2008 the author has had a strong academic connection to the European version of this competition, called Solar Decathlon Europe (SDE), and has followed, contacted and collaborated with a number of these projects since 2010, besides leading one and collaborating in two other competition entries with the UPC.

From over 100 projects reviewed, 20 have been selected according to their degree of approximation to the general definition of Living Labs as places for user-centered research in real-life settings, using open innovation and co-creation among multiple stakeholders, based on public-private or public-private-people partnerships.

In addition, their focus on sustainability in the field of architecture, with functions beyond that of a showroom for technological innovations, have been a criteria of selection, giving importance to a possible contribution to ESD for a larger community of users.

This selection has been limited to 20 projects in order to be able to obtain and process all relevant information and apply a structured analysis of each project, identifying different typologies and approaches. Around 50% of the projects are driven by universities and research institutes with strong industry participation, the other 50% are based on prototype housing,

[52] The search on the World Wide Web under the term "Living Lab", using Google search engine, resulted in 211.000.000 results in March 2013. In July 2015 the number of results was 40.800.000.

developed by universities in the context of the Solar Decathlon Competitions, a set of international university competitions for the construction of energy self-sufficient solar houses. Some of these prototype buildings (around 200 projects constructed since 2002 in 10 SD and SDE competitions) have been transformed after the competition into Living Lab projects with teaching, research and innovation activities linked to them.

The in-depth analysis of these projects allows a first evaluation of the state of the art of Living Labs in Architecture and to gain an initial overview of their different typologies, concepts, mechanisms, impacts and results. Many projects are located within the context of a research institute, a university or a public or private facility, benefitting from synergies and forming part of a greater infrastructure. This will be highlighted, as it contributes to the overall understanding and evaluation of a project.

Only a part of the analyzed projects describe themselves as Living Labs (8 out of 20), other denominations used are Community Lab, Application Lab, Neighborhood building workshop or Social innovation platform. Nevertheless, due to their characteristics, all selected projects can be initially considered Architecture Living Labs, a hypothesis that will be specified and discussed in the following chapters in order to be confirmed or not.

Each project description contains information about the following specific aspects:

- Name of the project
- Starting date (referring to the start as Living Lab, e.g. after a SD or SDE competition)
- Location of the project
- Main partners and stakeholders
- Objectives and goals (as described by the leading organization of the project)
- Type of laboratory
- Facilities and tools
- Concept
- Users (referring to the type of users, and the possibilities of user-centered research)
- Projects and activities
- Outcomes

In order to offer a clear overview, Annex II contains a summarized project data sheet for each of the 20 projects with additional graphic material and information, including an evaluation of its living lab approach according to chapter 5.

All information has been obtained from the following sources:

- Public available information and documents (publications, websites, blogs, reports)
- Online questionnaires by project leaders
- Contact via email with relevant persons involved and
- Personal interviews (personal meetings, Skype calls, telephone calls) with project leaders

After gathering and summarizing the information, the respective contact persons of each project have been consulted again about the correctness of the interpretation of the projects.

(Appendix 2: Project data sheets of 20 recent Architecture Living Labs)

4.3.1 Energy Efficiency Center (ZAE Bayern)

The Energy Efficiency Center of ZAE Bayern (Center for Applied Energy Research) is a **Research Center conceived as a demonstration building for novel, innovative, and energy efficient materials, systems, and technologies**, with the aim of demonstrating their exemplarily applicability. The center **started operation in 2013** and is located in Würzburg, Germany. [53]



Figure 4.20 Energy Efficiency Center ZAE Bayern, Würzburg
© Lang/Hugger/Rampp, ZAE Bayern

The main **stakeholder** is the Bavarian Center for Applied Energy Research (ZAE Bayern) with the support of institutional partners (Federal Ministry of Economics and Technology (EnOB-Research), City of Würzburg, Landesgewerbeanstalt Bayern (LGA), ETH Zürich) as well as private enterprises (WVV Würzburg, VR Bank Würzburg).

The objective of the project is to create a reference building implementing innovative techniques for research and demonstration purposes in order to set new standards. The project fosters research and development in the field of energy-optimized buildings by scientifically testing a range of novel developments.

Facilities and tools of the project consist of the research building itself, including offices, laboratories and a technical center as well as the corresponding infrastructures for the research activities of ZAE Bayern, allowing the development and practical performance testing of building components integrated in the demonstration building.

The underlying **concept** is that of a demonstration building with evaluation under conditions of real use. Additionally, an Information Center located at the main entrance informs visitors about the building concept and the applied innovative technologies, in order to disseminate the knowledge generated and transmit the results to a broader audience.

Users of the building are the employees, collaborators and partners of ZAE Bayern. Feedback from users, together with building monitoring and product and system evaluations, will provide indications of how certain technologies are performing, pointing out valuable optimization potential to manufacturers and planners.

Projects and activities are focused on technological research, i.e. on modular software, which allows the analysis of the energy demands and the emissions of a building in real time (Design Performance Viewer (DPV)), the integration of PCM (Phase Change Materials) for equalizing temperature peaks in interior spaces, highly insulating window frame systems of lightweight membrane roof constructions.[54]

Outcomes are product research and development activities together with the companies and collaborating research institutes, consulting services and patents, as well as publications and knowledge dissemination of applied research results to the broader public.

[53] http://www.energy-efficiency-center.de/en/Home (accessed July 2015)

[54] http://www.energy-efficiency-center.de/en/Home (accessed July 2015)

The **Energy Efficiency Center of ZAE Bayern** is a unique research facility, which **combines laboratory research and theory with practical evaluation of technologies** and materials in the **real-life environment** of a laboratory and office building.

Strong links to university and research institutes allow a **pluridisciplinary approach** to innovative projects together with a wide range of collaborating companies and the support of public administration and institutions. **User-centered** research is possible as the center's employees are working in the demonstration building and all necessary infrastructure and laboratory equipment is available for scientific evaluation under real conditions of use. **Co-creation and innovation activities**, i.e. through invited workshops, can take place with the participation of multiple stakeholders due to the concept of applied research of ZAE Bayern and the facilities of the center as a demonstration building.

4.3.2 Fraunhofer InHaus-Center (Fraunhofer)

Fraunhofer InHaus-Center, **founded in 2009**, is an **applied research center for developing, testing and demonstrating new solutions for rooms and buildings**, located in Duisburg, Germany.[55]



Figure 4.21 Fraunhofer InHaus at Duisburg, Germany

Its main **stakeholders** are several Fraunhofer Institutes (Fraunhofer Institute for Building Physics IBP, Fraunhofer Institute for Microelectronic Circuits and Systems IMS, Fraunhofer Institute for Software and Systems Engineering ISST, Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT) and more than 100 industrial partners.

The objective of the center is to develop, test and demonstrate new solutions for rooms and buildings and bring them to the market. Areas of expertise are the improvement of energy efficiency through the use of new materials, automated building services and the optimization of the design of office space and hotel rooms, the development and testing of innovative construction materials and intelligent building technology, and the improvement of security and assistance for people in care.

Facilities and tools consist in inHaus 1, a two floor pilot building dedicated to research for the residential sector and inHaus 2, a four floors pilot building dedicated to research for the commercial sector. InHaus 2 contains specific laboratory space like the Health Care Laboratory, the iRoom, the Elderly Care 2020 Laboratory, a Service Apartment as well as office and exhibition spaces.

The **concept** of inHaus Center is based on jointly planned and operated application labs, which allow an integrated chain of innovation from research through to application and the market. Cooperation with the inHaus Center is organized through joint research and development activities with the different Fraunhofer institutes and inHaus partner companies. Specific

[55] http://www.inhaus.fraunhofer.de/ (accessed Juny 2015)

partner categories that are offered vary from system partnerships to component partnerships, application partnerships and sponsorships.[56]

Users are mainly the participating researchers, experts and companies who develop, build, test and evaluate 1:1 prototype solutions in the specific application labs. User-centered research and user co-creation activities can be carried out through the participation of lead users, which can test and even live in some of the laboratories, i.e. in inHaus 1 as a fully functional single-family home.

Specific **projects and activities** of the center are focused on the areas of Building & planning with support from IT, Energy transparency & energy efficiency logistics and operating processes, Interaction between people and technology, multifunctional component building systems, sustainable construction, performance-oriented rooms, security and safety as well as electronic systems for assisted living.

Outcomes are mainly patents, product and service developments, innovation services, publications as well as knowledge generation and dissemination.

Fraunhofer inHaus-Center belongs to the Fraunhofer Gesellschaft, Europe's largest applied research organization, and has a powerful concept to offer which includes an **integrated chain of innovation from research through to application and the market**, based on application labs. Laboratories simulate **real-life environments** for testing and evaluating products and solutions under almost real conditions of use. **Pluridisciplinarity** is guaranteed through the huge variety of research institutes as stakeholders, a close link to higher education institutions and the large number of companies from different areas who participate as partners. In recent documents, the center describes the inHaus method as **Open Innovation in Living Labs**.[57]

4.3.3 City-zen Test Living Lab (Amsterdam Nieuw-West)

City-zen Test Living Lab is a **showcase home for innovative energy efficient energy and retrofitting technologies** in the city district Nieuw-West in Amsterdam planned to be **opened in 2015.**



Figure 4.22 City -Zen Test Living Lab Amsterdam

The main **stakeholder** is Amsterdam Smart City (ASC) as Public-Private-People-Partnership with a wide range of founding partners from public administration to higher education institutions and companies, and more than 150 project partners.[58] Four specific companies (Liander, Alliander, Daikin, Mastervolt) collaborate in the City-zen Test Living Lab.

[56] idem
[57] http://www.inhaus.fraunhofer.de/content/dam/inhaus/en/documents/English_PP_Standardpräsentation_Fraunhofer-inHaus-Zentrum.pdf (accessed July 2015)
[58] http://amsterdamsmartcity.com/ (accessed July 2015)

The objective is to display and test innovative solutions for buildings in the field of energy efficiency, including experiments about how to encourage the user to make "green choices", and also to scale up innovative energy solutions and open networks.

Facilities and tools consist of a standard house at the city district Nieuw-West in Amsterdam, with the necessary infrastructure for showcasing innovative technologies related to the scale of housing and knowledge dissemination about smart energy technologies and concepts on the city scale.[59]

The concept is that of a showcase home linked to a European research project, City-Zen – New urban energy[60] (EU FP7 project), and part of a citywide initiative, the "Smart Energy Lab Amsterdam".

Users of the project are neighbors of the city district and also external visitors. They will participate in behavior change experiments and knowledge dissemination activities of the Living Lab.

Specific **projects and activities** will focus on technological research and innovation like hybrid heat pump technologies (combined gas and renewable energy sources) and also projects on social innovation like a virtual power plant that allows city residents to trade energy. Linked to the overall European Project City-zen, synergies will be established with other projects i.e. on Serious Gaming, focused on energy saving through raising awareness and behavior change, or smart grids and sustainable district heating solutions.[61]

No specific **outcomes** are reported, as the project is not yet implemented at the date of writing.

City-zen Test Living Lab brings research and knowledge directly to citizens through a technology showcase as a Living Lab facility in a city district, open to all interested publics. The project forms **part of a wider initiative**, the Amsterdam Smart City project, **creating synergies** at all levels to generate **social impact and promote reflection** and progress towards a more **sustainable lifestyle** at all scales of society. It is based on a **Private-Public-People Partnership (PPPP)**, allowing to some extent **user-centered research** activities, although **user-co-creation** is limited, and outcomes are the result of the specific Test Living Lab. Beyond that, the advantages of the showcase building are still to be demonstrated.

[59] http://amsterdamsmartcity.com/projects/detail/id/85/slug/city-zen-test-living-lab?lang=en (accessed June 2015)
[60] http://www.cityzen-smartcity.eu (accessed June 2015)
[61] http://www.cityzen-smartcity.eu/demonstration-sites/amsterdam/ (accessed June 2015)

4.3.4 Living Lab. (TU Delft, European FP7 project)

The Living Lab is a European FP7 project, led by Delft University of Technology (TU Delft)
The project developed **between 2008 and 2010 as** a concept for a **standardized European research infrastructure for researching human interaction with and stimulating the adoption of sustainable, smart and healthy innovations around the home**.[62]



Figure 4.23 Design proposal Living Lab.

The main **stakeholders** of the project are Delft University of Technology as project leader, together with university and research partners (ETH Zürich, Universidad Politécnica de Madrid (UPM), Wuppertal Institute for Climate, Environment and Energy) as well as companies (ACCIONA, BASF, Procter & Gamble).

The objective of the project is to address environmentally critical forms of consumption and to contribute to the realization of more sustainable households in Europe. This requires understanding and modeling of the way physical/technical interventions in the domestic environment change the behavior of household consumers, in order to quantify its effects on overall sustainability performance. Developed behavior-change models can then be confirmed by evaluating their predictive quality for sustainable change of behavior in a realistic setting.[63]

Facilities and tools are modular housing units as standardized LIVING LAB research infrastructure with common basic layout and functions, but flexibility is adapted to local culture, climate and research interests.

The **concept** of the project is that of a **cross-cultural and cross-climate research living lab** as part of a research infrastructure of networked living lab houses across Europe. The project provides access to large numbers of users, generating insights into living behavior with data recorded via user-reporting and non-obtrusive observational techniques.[64] The specific projects will be developed and managed together with local universities, research institutes and companies at different locations in Europe.

Users of the project are the European research community together with collaborating companies. User-centered research and user co-creation activities can be carried out together with temporary residents or users of the homes.

Projects and activities would be focused on energy-efficient techniques and products for the home, domestic products and techniques that use renewable energy sources as well as water-saving techniques and products for the home.[65] The project has not yet been implemented. Stakeholder participation workshops including co-creation activities have been carried out in order to develop a powerful concept. No **outcomes** beyond project reports on stakeholder participation workshops and documents about concept development are available to date.

[62] http://www.livinglabproject.org/ (accessed June 2014)
[63] idem
[64] idem
[65] idem

The concept of the **Living Lab Project,** focused on the creation of real functional homes, together with facilities for research of user behavior and technical performance in **one single infrastructure,** allows carrying out **user-centered research** and **user co-creation** activities through an active participation of temporary residents of the homes. The open, cross-cultural and cross-climate concept fosters the possibility to implement **open innovation** activities with a broad range of stakeholders in a **real-life setting** all over Europe. The project is not yet implemented and needs to show its validity as a research infrastructure.

4.3.5 Cubity (TU Darmstadt)

Cubity is an **Experimental Plus-Energy Student Residence**, designed and built by a student team of Technische Universität Darmstadt (TUD) for the Solar Decathlon 2014[66]. After the competition, this project has been rebuilt at the TUD campus at Darmstadt and **since 2014,** forms part of an overall strategic development called "*Solare Lichtwiese"* (Solar Field). (See also chapter 3.6.10)



Figure 4.24 Cubity Student Residence TU Darmstadt
© Thomas Ott

The main **stakeholder** of the project is the Technische Universität Darmstadt (TUD) with the strong support of public administration, institutions and companies.

The objective of the project is to foster research and experimentation regarding living space for students, mainly affordable student housing with Plus-energy standard, through a prototype building which can be occupied and monitored and evaluated under real conditions of use regarding its energy and social aspects.[67]

Facilities and tools of the project is the student residence prototype building itself with modular student housing units for 12 inhabitants, consisting of minimized private space of approx. 7m2 per individual unit and a jointly used hall of 16m x 16m, as shared space with kitchen unit, living area and semi-private access areas to the individual modules. Support is given and synergies are generated through other infrastructures of TUD "*Solare Lichtwiese*" and the university in general regarding the maintenance, monitoring and evaluation of Cubity.[68]

The concept of Cubity is that of an experimental residential project, which explores co-housing concepts with shared equipment and a central "market place". The project revolves around aspects of flexibility, modularity, transportability, new types of living, renewable energy systems and favorable building costs. As a permanent student residence at the TUD campus, it forms part of their experimental construction activities, relating to the campus as a laboratory with 1:1 prototype buildings for teaching and research.[69]

[66] http://www.solardecathlon2014.fr/en/ (accessed July 2015)
[67] www.solardecathlon.tu-darmstadt.de (accessed July 2015)
[68] idem
[69] idem

Users of the project are the members of the academic community, students living in the residence building and experimenting with a different form of living, and researchers carrying out research about, and in collaboration with, the inhabitants.

Specific **projects and activities** will be centered on the evaluation of social and energy aspects during a 3-year monitoring period at the TUD "Lichtwiese" Campus under real conditions of use as student housing.

Outcomes beyond the building itself have not been generated yet due to the early stage of the monitoring and evaluation process.

Cubity is a **unique experiment about new forms of collective living** through a minimization of private space and the maximization of shared collective space in a student residence project. Its authors describe the project as a **Living Lab**, as it will be monitored and evaluated under **real conditions of use**, with a **user-centered research approach**, focused on the occupants and their personal living experience. This can lead to fruitful collective **co-creation and innovation processes** for further improvement of the concept of its architectural and energy concepts as well as its social dimension. Important knowledge can be generated through this field evaluation process for future housing concepts as well as **knowledge dissemination** towards a considerable collection of users and visitors, guaranteed through the location at a university campus and its regular use as student housing, allowing personal experience-based learning to students.

4.3.6 Rural Studio (Auburn University)

Rural Studio – *House for poor people* is an undergraduate program of the School of Architecture, Planning and Landscape Architecture at Auburn University. It is **an off-campus design-build program** established **in 1993**.[70]



Figure 4.25 Rural Studio: House for poor people

The main **stakeholders** of the project are Auburn University, School of Architecture, Planning and Landscape Architecture as organizing institution of the program, and donators of the individual projects who are generally companies or individuals.

The objective of the project is to give architecture students a more hands-on educational experience attending at the same time an underserved population in West Alabama's Black Belt region, with its specific needs for housing and community facilities.[71] Projects are designed, built and evaluated together with participating stakeholders like communities, individual tenants or the administration.

Facilities and tools of the project consist of an open warehouse in the Auburn University Campus, with materials and construction tools and the force of volunteers participating in the program.

[70] http://www.ruralstudio.org (accessed July 2015)
[71] idem

Conceptually each project becomes a new and different laboratory of experimentation and development within the overall project. The main work is developed by Auburn University with contributions from companies and private donators.

From **projects** based on recycling, reusing and remaking, the project focus has shifted since 2001 towards community-oriented work, always questioning what should be built rather than what can be built, for both the performance and operation of the projects.[72]

Users are students and faculties who work within the community, together with clients or "end users", in order to define solutions, fundraise, design and ultimately, build projects. Exhibitions and events for raising awareness of people, allow even more to participate and learn through the projects.

Since 1993 the undergraduate program has generated more than 150 projects as **outcomes** and educated more than 600 "Citizen Architects".[73]

Rural Studio – *House for poor people* can be understood as a **community laboratory** with multiple stakeholders (university, administration, companies, and private donators, as well as citizens and communities as beneficiaries) which collectively **co-create** solutions for improving the quality of life in the social context of a university. The "living" character of this type of laboratory is reinforced through its **participatory approach** among multiple stakeholders, co-creating solutions and the accompanying **research, centered on the user(s)** of the project, i.e. individual tenants or the members of a community, analyzing needs to collectively define the demands and provide solutions, always focused on **the real-life environments** of society.

4.3.7 Les Grands Ateliers (Grenoble)

Les Grands Ateliers is a **large-scale construction facility for experimental building activities**, founded in 2001, financed by Region RhónAlpes, and developed by a group of higher education institutions from Rhône-Alpes (ENSA Grenoble, ENSA Lyon, ENSA St Etienne, ENSA Clermont-Ferrand, ENSA Montpellier, ENSA Paris Malaquais, ENTPE, INSA Lyon et le CSTB). It's located at Villefontaine, France.



Figure 4.26 Les Grand Ateliers, Grenoble

The main **stakeholders** of the project are higher education institutions and specifically Schools of Architecture, with the support of strong industry collaborations (Lafarge, CNBD, Serge Ferrari, Vicat, Sant Gobain, among others).[74]

The objective is to offer a platform for experimentation, co-creation and innovation of construction systems, and prototype buildings attending to social challenges like eco

[72] idem
[73] idem
[74] www.lesgrandsateliers.org (accessed July 2015)

construction and sustainable cities. This is done through an interdisciplinary, practice-oriented training for architecture students and professionals related to the construction sector.

The project consists of a large-scale construction space in an open warehouse, with materials and construction tools for experimental building activities.

The **concept** of Les Grands Ateliers is that of an experimental laboratory for building construction and construction culture, fostering educational research in innovative practice oriented teaching and learning, carrying out thematic educational sessions with mixed teams of researchers, practitioners and students, using extended research laboratories involved in a variety of application, work in collaboration with industrial and institutional partners. Different prototype buildings are some of the results with the potential to serve as Living Labs themselves.

Users of the project are students, faculties, professionals, researchers and companies, who design, develop, construct and evaluate different projects at 1:1 scale or participate in any other educational activity of the center. A user-centered research approach is possible for the evaluation of generated prototype buildings after completion or user co-creation in an early design or prototyping stage.

Projects and activities are mainly focused on educational modules for undergraduate and postgraduate students with up to 50 activities, 15 Schools of Architecture and 6000 students participating each year (2010). Projects have focused increasingly on environmental and eco construction with a strong relationship to real social problems and challenges. Specific projects carried out are: Cité de la construction durable, Solar Decathlon Europe 2012, Solar Decathlon Europe 2010, Concours végétal 2010, Fétes des lumières.[75]

Outcomes are a large number of experimental practice-based educational activities, publications, competitions entries, exhibitions, videos and 1:1 prototype buildings.

In the case of **Les Grands Ateliers**, it is important to differentiate between the **place where experimental architecture is conceived, built and tested** through a pluridisciplinary approach of multiple stakeholders, and the built objects, which can be a prototype to be tested under real conditions of use in a different location after its construction.

Experimentation, **co-creation and innovation** take place during the development of projects at Les Grand Ateliers, like the Solar Decathlon Europe prototype buildings Armadillo Box (SDE 2010)[76] and Canopea (SDE 2012)[77], built by student teams of ENSA Grenoble. Although active user participation is limited in this stage of the projects, and generally no active **user-centered research or user co-creation** is possible, general user needs are analyzed and also social challenges like sustainable living in cities or vertical farming and energy self-sufficiency based on renewable energies are addressed during this phase.

Once the prototype buildings have been finished, real users can test the projects, evaluate their performance, quality and comfort from a functional and personal point of view, giving feedback about concepts, systems, materials or products at all scales.

[75] idem
[76] http://www.ines-solaire.org/france/DT1309170462/page/Armadillo-Box.html (accessed July 2015)
[77] http://www.sdeurope.org/downloads/sde2012/ (accessed July 2015)

This second stage requires a structured approach to capture user feedback. Related to this user-centered research, user co-creation activities can be started in order to transform user feedback into innovation or further development of tested solutions, together with other stakeholders like companies or academic institutions.

This means that both, building workshop (Les Grand Ateliers as infrastructure for teaching, research and innovation) and outcome (prototypes as products to be tested under real conditions of use), can be considered **Living Labs** according to their specific program, applied methodologies and outcomes.

This type of approach could be defined as a **Living Lab ecosystem**, which through the application of Living Lab concepts generates outcomes which can be considered new Living Labs, once they have been activated as such.

4.3.8 The Living Lab (IESD) (De Monfort University)

The Living Lab (IESD) at De Monfort University (DMU) at Leicester (United Kingdom) is a project promoted by the university's Institute for Energy and Sustainable Development (IESD).



Figure 4.27 The Living Lab Monfort University
Source: www.dmu.ac.uk

The objective is to convert an existing university building of DMU, the Queens Building, into a **showcase for refurbishment under aspects of energy efficiency, with strong research on user-building interaction and user engagement**, the integration of renewable energies and energy management.

The detailed objectives of the project according to DMU are:

- *Demonstrate how to achieve (and eventually surpass) Government carbon reduction targets in a cost-effective manner.*
- *Showcase the latest technological approaches to building and energy management as well as innovative building user engagement.*
- *Be a resource for teaching and research into sustainability for buildings, energy and behavioral changes*
- *Inspire, teach and live best practice for other public sector buildings in the UK.*
- *Contribute to, and shape future research and policy in the field of buildings, energy and sustainability.*
- *Create positive energy building concepts for the purpose of research and development (i.e. producing and storing surplus renewable energy at certain times).*
- *Demonstrate best practice in innovative building user engagement.*[78]

[78] www.dmu.ac.uk/about-dmu/sustainability/the-living-lab.aspx (accessed July 2015)

Facilities and tools are a university building under real conditions of use, available university research facilities, and the DMU's Institute for Energy and Sustainable Development (IESD) as leading entity of the project.

The underlying **concept** is a project, which is open for stakeholders to develop joint research activities like piloting and exploring novel technologies under real conditions of use. Collaborations are planned with companies as well as strong links between educational and research activities.

The **users** of the project are the members of the academic community, carrying out research and innovation projects with participation of students, administration and private companies. Regarding a user-centered research approach, users like students, staff and visitors who daily use the building might be part of an evaluation process under real conditions of use, once the project has started.

No specific **projects or activities** have been carried out so far, and consequently no **outcomes** are recorded, as the project has not yet advanced beyond first university-industry contacts.

Despite the project not effectively starting yet, the concept of **Living Lab (IESD)** as a **conversion of a university buildings into a Living Lab** for teaching, research and innovation is very powerful, as it allows the participation of a large community of users and the combination of experience-based, experimental learning with the daily use and first-hand evaluation of innovative products, systems and solutions in **a real-life environment**. **User-centered research** is easily possible as the users are the members of the academic community itself. Based on this shared experience of a large group of stakeholders**, co-creation and innovation activities** can take place in order to improve the tested solutions or find alternative products or services.

Due to the implementation in a university building under real use, different disciplines can be easily linked to the project and an open, **pluridisciplinary approach** can be achieved, as well as knowledge dissemination and project visibility.

4.3.9 Show Me House (SD 2009) - *Solar Village* (Missouri S&T University)

The Show Me House is the Solar Decathlon 2009 prototype, designed and built by a student team of Missouri University of Science and Technology. After the competition, it has been rebuilt and **since 2009** it forms part of an **overall strategic development for research and teaching called *Solar Village***, located at Rolla, Missouri (USA). Up to now 5 prototype solar houses have been developed by Missouri S&T for the Solar Decathlon Competitions 2002, 2005, 2007, 2009, and 2013 with a new 2015 house under development at the time of writing.



Figure 4.28 Show Me House at Solar Village

The main **stakeholders** of all projects are Missouri University of Science and Technology (Missouri S&T) with its Office of Sustainable Energy and Environmental Engagement (OSE3), the Student Design and Experiential Learning Centre, as well as collaborating companies.

The objective of the Show Me House is to **allow users a personal living experience in an energy self-sufficient solar house**. The house, as all other prototypes at the *Solar Village*, is under regular use as student housing.

The *Solar Village* project on the other hand, has the objective to foster the development of research in the fields of Building Science, Electrical Distribution and Material Science with a focus on Renewable Energy and Energy Efficient Technologies. It promotes an eco-friendly lifestyle through the personal living experience of the inhabitants and serves as a platform for designing, engineering, constructing, and marketing of solar powered homes for the Solar Decathlon competition, partnering with numerous corporations for support and displaying a wide range of products.

The **facilities and tools** of the overall project consist of the Solar Decathlon competition houses SD 2002, 2005, 2007, 2009 and 2013 under regular use as student housing, specific equipment for monitoring of energy performance, and the general available university resources for teaching and research.

The concept is the exhibition of prototype solar houses under real conditions of use as student housing and the use of the houses as teaching objects for students, which can be monitored, visited and explored.

Users are mainly undergraduate students, who participate in activities related to the Solar Village and who can apply to live in one of the 5 solar houses.

Specific **projects and activities** are focused on monitoring and regular public events like the Earth day celebration or guided educational visits. Related to this research, a project on micro-grids is now running, employing alternative and renewable generation, advanced energy storage, and intelligent switching capabilities into a residential facility complex researching technological, legal and social barriers.[79]

Main **outcomes** are the prototype buildings in use within an overall development, the *Solar Village*, the related interactive educational concept for students and visitors, as well as applied research activities, project reports, publications and knowledge dissemination.

The **Show Me House - *Solar Village* project** supports the overall university mission regarding sustainability, defined in the following statement:

> *Missouri S&T are committed to leading and demonstrating sustainable practices in our educational mission. By balancing the environmental, economic, and social dimensions of sustainability in our daily operations, we provide a model to our students and society. The Strategic Sustainability Planning Committee (SSPC) is made up of faculty, staff, and students who are dedicated to promoting and guiding sustainability efforts on the Missouri S&T campus. The goal of the SSPC is to identify, promote, and develop concepts*

[79] http://ose3.mst.edu/ose3home/energy/solarvillage/

for the S&T campus and surrounding community, around the 3 tenants of sustainability, environmental stewardship, social equity, and economic feasibility.[80]

In this sense, according to the Missouri S&T, the project is **strategic for the university in its goal to exercise leadership in operational sustainability** on campus, modeling sustainability practices in daily operations and practicing environmental stewardship, as well as curriculum development and social outreach regarding sustainability. The project allows **user-centered research** through the surveys of inhabitants of the different solar houses. **The main driver of the project is the university**, although linked research projects, such as a smart energy grid project, are carried out in collaboration with companies and other institutions. **Co-creation activities** with users or among pluridisciplinary teams are limited, although the regular participation of Missouri S&T in the Solar Decathlon Competitions shows the continuity of the experience and prototype-based teaching approach of the institution.

4.3.10 SurPLUShome (SD 2009) - *Solare Lichtwiese* (TU Darmstadt)

SurPlushome is the Solar Decathlon 2009 prototype, designed and built by a student team of the Technical University of Darmstadt (TUD). It's the second **energy-positive or "Plus energy" home** built by TUD after their first contribution in 2007. **Since 2010** and after, having been exhibitied to the public in different locations in Germany and internationally, SurPLUShome is now located at the TUD campus *Solare Lichtwiese* (Solar Field) at Darmstadt, Germany.



Figure 4.29 surPLUShome, TUD
© Thomas Ott

The main stakeholders are the Technische Universität Darmstadt (TUD) with its Interdisciplinary Centre on Technological Research (CIT), the Special Program Sustainable TUD, as well as private companies and public funding agencies.

Objectives of SurPLUShome are to **showcase a Plus Energy Solar house and spread related knowledge and concepts** to all kind of collectives through guided visits, publications and presentations, and to use the prototype for long-term monitoring of systems and components regarding general performance and energy efficiency in collaboration with companies.

The project ***Solare Lichtwiese*** [solar field] has been originally conceived as a project for the construction of a "solar field" by using building-integrated photovoltaics to feed electricity into the power grid, creating a showcase and fostering a research network for TUD personal.
Today it is referred to as a **campus space for experimental prototypes** of solar architecture for teaching, research and innovation purposes.

Facilities and tools of the overall project are the prototype solar house surplus Home (SD 2009) itself, the resources of the Faculty of Architecture and related institutes for monitoring, research and teaching activities as well as other components of the *Solare Lichtwiese* like the Solar House (SD 2007) and Cubity, a Plus Energy Student housing project (SDE 2014).

[80] http://ose3.mst.edu/ose3home/campussustainability/strategicsustainabliltyplanningcommittee/ (accessed Juny 2015)

The concept of SurPLUShome at the date of writing is that of a prototype solar house, which can be monitored, visited and explored. Nevertheless, its use as a guesthouse at the campus for visiting academics is planned for the near future.

Users are the academic community of TUD and visitors. Students participate in research and evaluation activities. User-centered research and evaluation under real conditions might be carried out in the future, when the house will be used as guesthouse with permanent occupation as a home.

Projects and activities related to SurPLUShome focus on educational visits to all kind of public, from students to professionals of the building sector, monitoring and technical evaluations of systems and products as well as the temporary use of the building as a facility for meetings and seminars.

The main **outcomes** are lectures and knowledge dissemination activities regarding the prototype and energy positive buildings in general, publications of all kinds and product monitoring and validation related to the applied technologies together with companies and research institutes.

SurPLUShome is a price-winning prototype, which had raised the public awareness on plus-energy buildings and energy efficiency in general, and had a major contribution to knowledge dissemination about sustainable buildings in general. **User-centered research** and **co-creation** activities are limited as the house is not occupied as a home but used as a showroom for technologies as a laboratory for building integrated solar technologies and related energy devices.

4.3.11 Magic Box (SD 2005) – Campus Montegancedo (UPM)

Magic Box is the Solar Decathlon 2005 prototype, designed and built by a student team of Universidad Politécnica de Madrid (UPM). It is the **first of 3 energy self-sufficient solar houses**, which UPM developed for the Solar Decathlon Competition held in the United States with two other prototypes built in 2007 and 2009.



Figure 4.30 Magic Box UPM

The main stakeholders of Magic Box are Universidad Politécnica de Madrid (UPM) with its Solar Research Institute *Instituto de Energía Solar (IES)* and the Project specific collaboration of private companies.

Campus Montegancedo, designated Campus of Excellence by the Ministry of Education in the 2010, is a UPM campus project, focused on sustainable technological innovation, based on the creation of an open innovation ecosystem, applying science-driven and open innovation strategies.[81]

[81] www.upm.es/MontegancedoEN , accessed Juny 2015

In early documents, the UPM solar houses Magic Box (SD 2005), Casa Solar (SD 2007) and B&W House (SD 2009) have been mentioned to form part of this project, which includes Experience Labs and Living Labs which allow prototype development and testing, including user-centered research. Nevertheless at the date of writing no specific information could be found about the current location of Casa Solar and B&W House, or any activity related to these two prototypes, and the Magic Box prototype house is not located at Campus Montegancedo but on a different campus of UPM.

This compromises the initial concept of a test bed for energy efficient buildings at the campus, which would allow creating strong pluridisciplinary, user-centered research and innovation activities with different prototype solar houses at the same place.

The objective of Magic Box is to offer a **multidisciplinary laboratory for research and training on sustainable buildings, renewable distributed generation and intelligent control**. The goal is to facilitate the use of a SD prototype as research lab and demonstration site for solar energy in buildings and the possibilities of electricity demand management.

Facilities and tools of the project are the Magic Box prototype solar house itself together with the general university research facilities and infrastructures, available to carry out teaching and research activities, especially the infrastructure laboratory of the Solar Research Institute IES. Connection and mutual benefit between the Montegancedo campus project as well as the other two UPM prototype solar houses is weak.

The **concept** of Magic Box today can therefore be described basically as installation, testing and evaluation facility for technological innovations in the field of energy generation, use, management and storage in buildings.

Users are the academic community together with collaborating companies and visitors. No user-centered or user-driven research has been carried out so far; real occupation and evaluation under real conditions of use as housing or office space has not taken place yet.

Regarding **projects and activities** carried out, according to the project responsible Magic Box is nowadays used as laboratory where “students and young researchers, under the guidance of UPM's professors and researchers can have access to the installation and operational data for their practical degree activities and PhD research objectives”[82].

Regarding specific **outcomes**, 3 PhD theses and 1 innovation project regarding a distributed system for the active demand side management of domestic electricity demand (GeDELOS-PV system) have been linked to Magic Box since then.

A more ambitious project could not be implemented as “deep cuts in public R&D in Spain have not allowed developing initially foreseen research strategies and have also compromised resources for the Lab improvement.” [83]

Magic Box is mainly used as an ordinary laboratory-like monitored prototype building for technological research and related teaching and knowledge dissemination activities.

[82] Citation of Prof. Estefanía Caamaño (UPM), online questionnaire on Living Labs, July 2015
[83] idem

4.3.12 home+ *(SDE 2010)* (HfT Stuttgart)

Home+ is the **Solar Decathlon Europe 2010 prototype**, designed and built by a student team at Stuttgart University of Applied Sciences (HfT). After the competition, the project has been shown in different locations in Germany and has found its final location **since 2012** at a plot near the Faculty of Architecture of HfT at Stuttgart, Germany.



Figure 4.31 Home+ prototype HfT Stuttgart

Main stakeholders are Stuttgart University of Applied Sciences (HfT) with its faculty of Architecture as the main driver of the project, supported by the ZAFnet_Research Institute (HfT Stuttgart), several public institutions and organisms as well as private companies and social entities.

The objective is to convert home+ into a **Living Lab for research and teaching of energy efficient architecture**, fostering research and knowledge generation regarding building acclimatization and air-conditioning units with passive and active regenerative technologies.

Its **facilities and tools** consist of the home+ prototype itself, as an energy self-sufficient solar house together with the general university research facilities and infrastructures, available to carry out joint teaching and research activities.

The concept of the home+ Living Lab is that of a technological research project on energy efficient architecture and renewable energy in buildings, based on prototyping, testing and evaluation in a real building and under real conditions of use.

The director of the project describes 4 main functions of home+:

- *Living Lab: Location for seminars and lectures within the context of solar buildings and technologies.*
- *1:1 showcase.*
- *Lab for KlimaEngineering (Climate Engineering).*
- *Lab for further research at a component level and for integrated system design, control strategies etc.*[84]

Users are members of the academic community and visitors of the prototype. So far no user-centered or user-driven research under real conditions of use has been carried out, as the project has not been occupied permanently as housing or office space.

Specific **projects and activities** are educational visits for students and the general public. University – industry collaborations regarding development and testing of innovative PVT (Photovoltaic Thermal Collector) technologies have been carried out as well as the development and optimization of simulation tools for monitoring operation online, and an integrated building information management, control and simulation system in order to optimize energy flow and loads.

[84] Citation of Prof. Jan Cremers (HfT Stuttgart), online questionnaire on Living Labs, July 2014

The outcomes of the project are its successful installation as teaching and research infrastructure at HfT Stuttgart, educational activities carried out since then as well as technological research projects carried out with the corresponding publication of results.

Home+ is a price-winning prototype, which is used to raise public awareness on plus-energy buildings and energy efficiency in general, contributing to knowledge dissemination about sustainable architecture in general. **User-centered research** and **co-creation** activities are limited as the house is not occupied as a home but used as a showroom for technologies and as laboratory for building integrated solar technologies and related energy devices. Home+ received funding for its use as Living Lab and its integration into regular teaching and research activities at HfT Stuttgart.

4.3.13 Mobile Utility Unit *(SD 2002)* - *CMPBS* (UT Austin)

The Mobile Utility Unit is the **Solar Decathlon 2002 prototype**, designed and built by a student team of University of Texas in Austin (UT Austin). After the competition, **starting from 2002**, it has been "permanently parked"[85] at the CMPBS, Centre for Maximum Potential Building System at Austin, Texas. CMPBS today is the **main stakeholder** of the project.



Figure 4.32 CMPBS at Austin, Texas

The main **objective** is the use of the **solar house as an office and demonstration building, providing also occasional housing for interns and guests of the CMPBS**.
The center itself is focused on education, research, and demonstration with a specialization in life cycle planning and design. The center fosters ecological building and master planning design, policy and education initiatives such as green builder programs and offers sustainable design and LEED™ consulting services. It develops analytical tools for understanding and incorporation of sustainability principles. [86]

Facilities and tools of the project are the former SD 2002 prototype house itself but also the general facilities of CMPBS consisting in an 18-acre site with experimental structures such as the Advanced Green Builder Demonstration Home as well as a library and a metal and wood fabrication workshop, and lately the 2007 Solar Decathlon House of Texas A&T University.

Concept of CMPBS as a whole is that of a non-profit organization (the oldest of its kind in the United States) focused on sustainable design, research, and education, with prototype houses like the Mobile Utility Unit understood as a teaching tool and source of inspiration for students, researchers and visitors.[87]

Students and faculties are regular **users** of the building, learning, testing and evaluating, and even temporarily living in it. User-centered research has been possible due to the operation of the building under real conditions of use.

[85] http://www.solardecathlon.gov/past/2002/where_is_texas_now.html (accessed July 2015)
[86] www.cmpbs.org (accessed June 2015)
[87] idem

Projects and activities of CMPBS are the development of analytical tools that enable better understanding and incorporation of sustainable principles, e.g. the combination of GIS, input/output analyses of the U.S. economy, and life cycle data to address the balance of energy, food, water, air, and materials, its use as Advanced Builder demonstration site and the collaboration in design and construction of the Solar Decathlon prototype solar houses 2002 and 2007. [88]

Outcomes of the project are publications, protocols, prototypes and teaching and research activities. The Mobile Utility Unit forms part of the experimental building site of CMPBS, with regular open house events for the general public and continuous research and knowledge dissemination for students and professionals.

Mobile Utility Unit is today used as part of the CMPBS infrastructure, but no specific **user-centered research** is carried out anymore, as the building dates from 2002 and is now used as a regular office building. **Co-creation and innovation** activities are carried out by CMPBS but not specifically related to the prototype building.

4.3.14 Interlock house (SD 2009) (Iowa State University)

The Interlock House is the **Solar Decathlon 2009 prototype**, designed and built by a student team of Iowa State University. Sold after the competition to the Iowa Department of Natural Resources, the house has been located **since 2010** at the Honey Creek Resort State Park, Rathburn Lake (Iowa), accessible to the public as the **solar powered showcase home and interpretative center** of the Park, with educational activities about natural resources and environmental activities for park visitors.[89]



Figure 4.33 Interlock house

The main **stakeholder** is the Iowa State University with its Center for Building Energy Research (CBER), with support of DOE's National Renewable Research Energy Laboratory (NREL). Owner is the Iowa State Department of Natural Resources (DNR).

The objective is to maintain the house accessible to the public as showcase home with on-going monitoring and research by Iowa State students and faculty as a net-zero energy building under local climate. Nowadays the Interlock house is described as an "Activities Building and Nature Center"[90] of Honey Creek Resort State Park as well as **"residential community laboratory aimed at optimizing energy efficiency through design tools and strategies"**[91].

The **facilities and tools** of the project consist in:

- Former SD 2009 prototype house – the Interlock House.
- Additional basement below the house as space for educational activities.
- Equipment for monitoring building performance and as visitor center.

[88] idem
[89] http://www.solardecathlon.gov/past/2009/where_is_iowa_now.html (accessed June 2015)
[90] http://www.design.iastate.edu/news/10/2/2014/solar_tour (accessed June 2015)
[91] idem

According the project leader from Iowa State University, Prof. Ulrike Passe, the Interlock House today forms part of a series of "Iowa NSF EPSCOR Community Laboratories for Energy Utilization Research".[92] The initial lifespan is a 5 year funding period (starting 2012), but " the house is established as a field laboratory and further funding is currently pursued, and thus the lifespan may be long term. The data acquisition system has been set up for long term energy performance monitoring."[93]

The **concept** of the project is that of a showcase solar home, with use as long-term research and teaching laboratory for energy efficiency in buildings, allowing continuous monitoring activities regarding building performance under local climate conditions and conditions of real use.

Users are office employees, researchers, students and visitors who visit the building or participate in activities. The project also centers its research on the user, as the project leader ,Prof. Ulrike Passe, states: "The occupants play a strong role in the project and post occupancy, as well as visitor surveys which are coordinated with the research questions."[94] This means that user-centered research is carried out, although users are not drivers or co-creators in a participatory process.

Regarding specific **projects and activities**, the project aims to provide design guidelines for passive heating and cooling strategies in Iowa by making full use of solar radiation to heat the interior in winter, promoting natural ventilation to cool and refresh the interior air in mild seasons and integrating daylight design with spatial composition measurement data.[95]

At the date of writing, the project is financed within a 5-year project as "Iowa NSF EPSCOR Community Laboratory for Energy Utilization Research" in order to carry out simulation and study of natural ventilation and solar heating effects through thermal dynamic simulations and building monitoring. Testing of liquid desiccant dehumidification systems, day lighting research, weather data collection and the continuous monitoring of indoor temperature and humidity, electricity consumption as well as electrical and thermal energy production, are further activities which are carried out within this project.

It participated in Open House activities, organized by ASES (American Solar Energy Society) in 2014 and opens regularly for the general public.

Main **outcomes** are the successful implementation of Interlock House as a community laboratory for energy research, publications of research results and regular knowledge dissemination to the general public.

Interlock House is a successfully implemented project, which serves for the generation and dissemination of knowledge regarding sustainable energy efficient buildings in a specific local context. It allows **user-centered research** under real conditions of use. **Co-creation** and innovation activities are limited, and **stakeholders** are mainly university and administration, sharing a common interest in the infrastructure created.

[92] Citation of Prof. Ulrike Passe (Iowa State University), online questionnaire on Living Labs, Sept. 2014
[93] idem
[94] Citation of Prof. Ulrike Passe (Iowa State University), online questionnaire on Living Labs, Sept. 2014
[95] http://iowaepscor.org/research/energy/utilization/buildingscience (accessed June 2015)

4.3.15 Living Lab LOW3 (UPC)

Living Lab LOW3 is based on the **Solar Decathlon Europe prototype LOW3** (SDE 2010) of the UPC, developed by a student team of its School of Architecture ETSAV and under direction of the author.



Figure 4.34 Living Lab LOW3, ETSAV (UPC)

The project **started in 2010** with the reconstruction of the solar house at the ETSAV campus at Sant Cugat del Vallès (Barcelona). The ETSAV School of Architecture is the main stakeholder of the project with many administrative partners (City of Sant Cugat del Vallès, Catalan Energy Institute (ICAEN)) and companies (KIC InnoEnergy, Rehau, VGP) collaborating and funding the project.

After participation in the competition, the **objective** has been to convert the LOW3 prototype into a **Living Lab as an experimental platform for teaching and learning about sustainable architecture, sustainable lifestyle and ESD**. The project aims to foster technological research and education on sustainable architecture, energy efficiency and renewable energies through designing, testing and evaluating experience-based, participatory learning methodologies, strategies and tools regarding ESD at the campus of a school of architecture.

The **facilities and tools** of the project consist of:

- A fully functional solar house for real living experiences including data evaluation equipment (OWL energy monitoring, TESTO datalogger, house monitoring system).
- Space and equipment for explorative and experimental educational activities with exhibition space for materials and technologies.
- Space and equipment for seminar activities and temporary events like open doors days.

Its **concept** is based on the idea of a platform for collaborative and participatory learning activities regarding ESD in general with a focus on sustainable architecture and lifestyle. It offers temporary support for bottom-up initiatives and projects as well as temporary working or exhibition space for collaborating companies, benefitting both from synergies with other ETSAV campus facilities like the PAuS Experimental Platform, the Solar Cube BIPV Laboratory, the ETSAV building workshop, and the two following Solar Decathlon projects e(CO) (SDE 2012) and RESSÒ (SDE 2014).

Users are understood as important drivers for teaching, research and innovation activities: PhD students, postgraduate students, undergraduate students are highly implicated in different activities, and also external visitors (scholars, citizens, professionals) benefit from the installations. Users as house occupants give feedback on concept, systems and products installed in the prototype, and allow resource consumption and lifestyle impact of inhabitants to be evaluated through a **user-centered research** approach (Live-at-LOW3 Experiment 2012).

Projects and activities are focused on Educational Research and Innovation, especially through the Living Lab approach (Living Lab Learning Module KIC InnoEnergy 2011-12).

Teaching activities have been carried out at all levels, from Elective Undergraduate and Master courses (2011-12), Educational guided visits and explorative activities (2012- on-going) up to Regular co-creation and innovation seminar activities on Master and PhD level (2013 – on-going)

A house occupation experiment "Live-at LOW3" (2012) allowed the evaluation of the prototype under real conditions of use as student housing for two people. The experiment was designed and carried out by students at Master level (Master Sustainability, UPC) with a holistic research and evaluation of sustainable lifestyle parameters.

Industry research collaborations have been carried out (Rehau Industries 2011, Valldoreix Green Power (VGP) 2013) in the field of technical building installations (solar thermal and HVAC) and concentrated solar PV systems.

The Living Lab offers its spaces regularly as meeting room for project development and networking for student initiatives.

Main **outcomes** are its regular teaching activities, several Master and PhD thesis projects linked as well as publications about its concepts and results as innovative infrastructure for teaching, research and innovation.

4.3.16 Pas a Pas (UPC)

Pas a Pas is a project based on the **Solar Decathlon Europe prototype e(co)** (SDE 2012) of UPC, developed by a student team from its School of Architecture ETSAV and with support from the author. After the competition, the solar house was stored at the ETSAV campus with some modules used as temporary working space for the e(co) student collective, developing the concept for its future use. **Since 2015** the project has been located at the Les Planes neighborhood of Sant Cugat del Vallés, near to the ESTAV campus, as a **community lab and place for meeting and organizing neighborhood initiatives**.



Figure 4.35 Pas a Pas project, Les Planes

The main **stakeholder** is the City of Sant Cugat del Vallés (Barcelona), together with Les Planes Neighborhood Association, Aruba Association (former e (co) student collective) and ETSAV (UPC) as university and author of the project.

The Objective of the project is to establish and support neighborhood initiatives in the field of energy refurbishment and general improvement of housing and community spaces.

The facilities and tools of the project consist of the energy self-sufficient prototype solar house e(co) (UPC, SDE 2012) adapted in a new constellation to the local site and the new program, equipment for meeting and working, monitoring equipment for indoor comfort control and basic equipment for a building workshop.

The **concept** of Pas a Pas is that of a neighborhood building workshop and platform for social innovation regarding energy efficiency, collective space and sustainable lifestyle.

The users are the neighbors of the community who actively participate in the planning and execution of refurbishment activities, improving their own homes, that of their neighbors, as well as community infrastructure and spaces. The aim is to activate neighbors as drivers of this process.

Projects and activities are focused on the analysis and evaluation of building standards of neighborhood buildings through monitoring, collective development and execution of refurbishment concepts for housing and public spaces, and general coordination of neighborhood participatory processes and workshops.

The Outcomes are specific neighborhood refurbishment projects, executed successfully like the energy refurbishment of the roof construction of several houses or the refurbishment of the sports facility.

Pas a Pas is a **unique neighborhood building workshop and platform for social innovation**, which activates synergies among neighbors, administration, university and private companies through a public-private-people partnership (PPPP), in order to collectively improve the quality of life of citizens. It's about monitoring, intervention and evaluation in the **real-life environment** of a community through a pluridisciplinary approach, with the user as active participant of the project. **User-centered research** through user surveys, observation and monitoring forms part of the process, **co-creation and innovation** activities are basic underlying principles and considerable **outcomes** could be generated in a relatively short time.

4.3.17 Ressò (UPC)

Ressó is the **2014 Solar Decathlon Europe prototype** from the UPC, developed by a student team of its School of Architecture ETSAV with support of the author. After the competition, the solar house was stored with the Ressó student collective developing and managing the concept and necessary agreements for its future use.



Figure 4.36 Resso prototype at Versailles (SDE 2014)

From 2016 on the project will be located at the Sant Muç neighborhood at Rubí (Barcelona), near to the ESTAV campus, as a **neighborhood co-housing facility for meeting and organizing neighborhood initiatives**.

The main **stakeholders are** the City of Rubí (Barcelona), together with Sant Muç Neighborhood Association, the Ressò student collective of ETSAV, and ETSAV (UPC) as university and author of the project.

The main **objective** is to create a neighborhood facility for a low-density neighborhood near to the UPC in order to foster knowledge and neighborhood action in the field of energy efficiency, renewable energies and sustainable lifestyle, offering a place where social innovation and networking can take place.

The project aims to foster applied research initiatives about sustainability, e.g. co-housing or renewable energies in low-density urban environments, and to spread knowledge and experience of construction, refurbishment and use of low impact buildings in the Mediterranean climate.

Finally, the project fosters the development and application of low impact technologies and new constructive solutions especially for the refurbishment of the existing building stock of the neighborhood.

Facilities and tools of the project consist of the energy self-sufficient prototype solar house Ressò (UPC, SDE 2014) adapted to the local site and the new program, and equipment for a co-housing unit, for meeting and working as well as monitoring equipment for indoor comfort control.

The **concept** of the project is that of a Neighborhood building workshop and platform for social innovation.

Users of the infrastructure are mainly the members of the local community, which together with other stakeholders initiate processes of improving sustainability parameters of the neighborhood (mobility, energy, social innovation). Users are foreseen to be the main drivers of the process.

Projects and activities are focused on the evaluation of building standards of neighborhood buildings (private homes), educational initiatives for knowledge dissemination about energy efficiency and renewable energies as well as the collective development of refurbishment concepts for housing for the people involved. Other future activities will be the coordination of neighborhood participatory processes and workshops.

Outcomes so far are limited, as at the time of writing the project is in the process of construction in the Sant Muç neighborhood. Workshops with citizens have been organized and the first articles about the project have been published.

Ressò is a **unique neighborhood co-housing facility for meeting and organizing neighborhood initiatives**, which activates synergies among neighbors, administration, university and private companies through a public-private-people partnership (PPPP), in order to collectively improve the sustainability of the community i.e. in the fields of mobility, energy and social innovation. It's about monitoring, improvement and evaluation of sustainability related parameters in the **real-life environment** of a community through a pluridisciplinary approach, with the user as active participant in the projects. **User-centered research** through user surveys, observation and monitoring forms part of the process, **co-creation and innovation** activities are basic underlying principles and considerable **outcomes** are expected once the project is fully implemented.

4.3.18 LIMA (SaAS / La Salle – Universitat Ramon Llull)

LIMA (Low Impact Mediterranean Architecture) is a research initiative which generated a concept for a **low impact prototype home** of the same name developed and built in **2009** by SaAS Architects, a private architecture firm, together with a research team of universities and consultants and more than 40 companies from the sustainable construction and energy efficiency sector.[96]



Figure 4.37 LIMA prototype house at URL Campus (Barcelona)

The main **stakeholder** of the project today is the SaAS architects office together with institutions and companies as members or collaborators of the **LIMA association**, a "nonprofit association composed of professionals from different parts of the building sector that are working to ensure a paradigm shift in the construction sector that could generate a standard for very low environmental impact construction []"[97].

The prototype has been monitored in a first phase in standardized conditions at the Engineering and Architecture Campus of La Salle (Universitat Ramon Llull) in Barcelona. In a second phase the prototype is currently **monitored in conditions of real use** as an office building in Sant Cugat del Vallès (Barcelona).

Objectives of the LIMA initiative are:

- *To generate a low impact constructive standard that would become in a real alternative to construct houses and other type of buildings, rather in new constructions than in refurbishments.*
- *To bring together and coordinate applied research initiatives about the sustainability of Mediterranean urban environments.*
- *To design, test and apply tools to evaluate sustainability in construction, refurbishment, and use of buildings in Mediterranean urban environments.*
- *To spread the generated knowledge and results about construction, refurbishment and use of low impact buildings, at the Mediterranean and internationality.*
- *To stimulate the development and application of low impact technologies and new constructive solutions, for new buildings and refurbishment.*[98]

In this sense, the LIMA prototype serves as a fully functional low-energy house for a real living experience with data evaluation equipment for performance evaluation under Mediterranean climate conditions.

Facilities and tools consist of the prototype building itself and data acquisition systems for comfort evaluation, performance monitoring and system control.

The Concept of LIMA is that of a prototype building or showcase, which allows data of interior comfort conditions, energy demand and energy consumption to be obtained, as well as

[96] www.lima.cat (accessed July 2015)
[97] idem
[98] idem

monitoring data of solar thermal energy generation, solar PV electricity production and water consumption, in order to evaluate the energy efficiency of different technological solutions and systems, and the overall performance of the building under real conditions of use.

Users are the academic community, collaborating companies, visitors and office employees. User-centered research can be carried out, as the building is currently in regular use as an office building.

Projects and activities regarding the **LIMA prototype** are focused on monitoring under real conditions of use, first simulating different scenarios of occupation and currently in use as regular office space. The knowledge generated is disseminated through participation in an international research project regarding nZEBS's (nearly Zero Energy Buildings) of the IEA (International Energy Agency).

The **LIMA association** is active in the management of the LIMA prototype evaluation, offers services on building and urban environmental sustainability evaluation, and organizes workshops and technical seminars as well as collaborates with organizations and institutions for knowledge generation and further implementation of Low Impact Mediterranean Architecture.

LIMA is a non-typical project, as its origin is based in the **initiative of a private architecture firm** to design and construct a low energy prototype building for the Mediterranean climate together with companies and experts of **different disciplines**. This has given place to a **public-private partnership** with university and research institutes and the creation of a non-profit association for professionals interested in very low environmental impact architecture. The resulting prototype home is tested **in real-life environments** as an office building, **user-centered research** has been carried out to a limited degree and **outcomes** have been disseminated broadly.

4.3.19 Prototype 1 - *Concept House Village* (CityPorts Academy Rotterdam)

Concept House Village (CHV), a **sustainable prototype home for user-centered research**, is an initiative from CityPorts Academy Rotterdam and is executed by Rotterdam University of Applied Sciences, Delft University of Technology and Woonbron Housing Cooperation.[99]



Figure 4.38 Prototype 1 – Concept House Village, Rotterdam

The main **stakeholder** of the project, **built in 2012**, is the CityPorts Academy Rotterdam as a foundation in which the City of Rotterdam and Port of Rotterdam are working on large-scale redevelopment of the city's port area with the aim to convert the cities' low-quality social housing stock into attractive neighborhoods for middle incomes. The foundation includes a large group of public authorities, research and education institutions and businesses, including Rotterdam University of Applied Sciences, Arcadis, Public Works Rotterdam, Woonbron Housing Cooperation and Delft University of Technology.

[99] http://concepthousevillage.nl (accessed July 2015)

CPA initializes, stimulates, coordinates and facilitates research and development projects including the Concept House Village where innovative, green, attractive living concepts are demonstrated for future large scale roll-out.[100]

The Objective of the Concept House Village is to facilitate a place where innovative, green, attractive living concepts can be demonstrated and tested for future large-scale rollout. The project aims to create a Living Lab for demonstration and testing of innovative houses, products and systems under real conditions of use, by and with real occupants.[101] Stakeholders and partners are stimulated to participate in co-creation and innovation activities generating and sharing knowledge. Research is carried out at an urban level, building level and product level.

Prototype 1 serves to showcase the latest technologies regarding sustainable energy, water, sanitation and intelligent homes in order to contribute to a more sustainable built environment. The apartment-laboratory facilitates monitoring, evaluation and user-centered research under real conditions of use.

The Concept of the Concept House Village is that of a Living Lab where innovative houses, products and systems are tested with and by occupants.[102] Through a direct link to research and education innovation processes can be accelerated and synergies can be generated between different activities.

A team of developers from Delft University of Technology was first to develop a Concept House with the construction of Prototype 1. A second house, CHIBB, has just been finished at the date of writing.[103] As an energy self-sufficient, factory prefabricated apartment using sustainable materials and technologies, Prototype 1 serves to carry out monitoring, testing and evaluation activities on products and services around the home with the occupant participating in the process.

Facilities and tools consist in the prototype building itself as well as the Concept House Village as a whole with its managing and technical infrastructure.

Users of the facilities are all consortium members who participate in the specific projects, academic community through linked teaching and research, as well as the general public. **User-centered research** can be carried out through real occupation and use of the prototypes.

Projects and activities are focused on the areas of usability, building and demolition potential and technical functioning of the prototype, as well as in educational activities and general knowledge dissemination towards society.

Outcomes are a real functional prototype, monitoring results, publications, and positive impact through knowledge dissemination.

As a 'Living Lab' **Prototype 1** forms part of the international research project SusLabNWE, aimed at the testing, developing and marketing of concepts that lower the energy use in the home environment.

[100] http://suslab.eu/partners/cityports-academy/ (accessed July 2015)
[101] http://concepthousevillage.nl (accessed July 2015)
[102] http://concepthousevillage.nl (accessed July 2015)
[103] idem

For this purpose, Suslab offers an international research facility with Living Labs and existing households in four participating countries: the Netherlands, Germany, Great Britain and Sweden.[104] **Prototype 1** offers a **user-centered research facility** with a strong focus on knowledge dissemination to the general public but also through its link to research and teaching. **Co-creation and innovation** activities are the main strength of the project, although specific results still have yet to be published.

4.3.20 PlaceLab - *House_n* (MIT)

PlaceLab is an apartment-laboratory designed, built and operated **since 2008** by the House_n Research Group of the MIT School of Architecture as a highly flexible and **multi-disciplinary observational research facility** for the scientific study of people and their interaction patterns with new technologies and home environments.[105]



Figure 4.39 House_n facilities, MIT

The main **stakeholder** is the MIT - House_n Research Group together with TIAX, a technology processing and commercialization company. The fully functional apartment is located in a residential condominium in Cambridge, Massachusetts.

The objective is the development of innovative user interface applications that help people control their environment, save resources, remain mentally and physically active, and stay healthy through sensors installed in the home. Through detailed monitoring of activity in the environment, researchers can study how people react to new devices, systems, and architectural design strategies in the complex context of the home.[106]

Facilities and tools of the project consist of the PlaceLab facility with hundreds of sensors and observational infrastructure working as a multi-disciplinary shared scientific tool, together with the supporting infrastructure of house_n research group such as a portable toolkit of sensors and remote monitoring devices.

The **concept** of PlaceLab is that of multi-disciplinary observational research facility. Through an open submission process researchers of different disciplines can submit proposals to use the PlaceLab in order to study aspects related to life in the home, i.e. regarding effective technology, behavioral change through architectural design, resource efficiency, learning and innovations for improvements of everyday life.[107]

[104] www.suslab.eu
[105] http://web.mit.edu/cron/group/house_n/placelab.html (accessed Juny 2014)
[106] idem
[107] idem

Users of the project are mainly researchers and collaborating stakeholders such as companies who use the infrastructure for their studies. **User-centered research** is carried out through volunteers who agree to live in the home for varying lengths of time allowing registration and observation of their daily activities and behavior patterns.

Projects and activities are centered on observational research of user behavior. The experimental occupation of the apartment-laboratory has taken place several times and different studies have been carried out. Despite the innovative approach of the project and the heavy investment in technological infrastructure and design of the facility, little **outcome** is documented and only viewable information is available about the studies carried out since 2008.

PlaceLab is a groundbreaking approach to a **multi-disciplinary** observational research facility in the **real-life environment** of an apartment, which can be occupied regularly for the purpose of **user-centered research** regarding behavior patterns of users in domestic environments, i.e. in the fields of user-technology interaction or design for behavioral change. **Co-creation and open innovation activities** can be linked to the project with a multiple stakeholder approach, allowing the testing of prototype technologies or products under real conditions of use.

4.3.21 Discussion

The **20 selected case studies** of recent Living Labs in Architecture presented here allow a first comparison between projects, focusing on their **different approaches to innovation** and establishing similarities and differences.
It can be stated that different types of stakeholders have developed different concepts of Living Labs with different objectives. Furthermore, **user groups** are different, and the role of users regarding a typical living lab **user-centered research approach** varies widely between projects from **user observation to user participation and co-creation**.
In the following, the differences and similarities detected are described in order to allow a first characterization of Living Lab projects, serving as an introduction for the development of a detailed evaluation tool and descriptive differentiation in chapter 6.

Stakeholders of Living Labs in Architecture

6 different kinds of main stakeholders may be identified, with the majority of the projects (9) being driven by universities and public administration (5) or public research entities (3):

- **University** (Rural Studio, Cubity, Living Lab IESD, ShowMe House, SurPLUShome, Magic Box, home+, Living Lab LOW3, PlaceLab)
- **Public administration** (City-zen Test Living Lab, Les Grands Ateliers, Interlock House, Pas a Pas, Ressò)
- **Public Research Entity** (Energy Efficiency Centre, InHaus Center, Mobile Utility Unit)
- **European research consortium** (Living Lab.)
- **Private entity** (LIMA)
- **Public foundation** (Prototype 1)

In some cases it is not totally clear who is the main stakeholder, i.e. Les Grand Ateliers (case study R07) is financed by public administration, but driven by a pool of universities. Pas a Pas (case study R16) and Ressò (case study R17) have public administrations (cities) as official main stakeholders, but a university is an important driver of both projects and their related infrastructures.

Concepts of Living Labs in Architecture

In the following, the different concepts behind the case studies presented are listed in order to offer an overview of the wide range of project definitions found in this research.
Although a considerable number of projects have their origins in prototype solar houses, developed and built by universities for one of the Solar Decathlon competitions, their post-competition concepts vary considerably being used as **technology research labs, showcase homes, community laboratories, co-housing neighborhood facility** or **office space under evaluation**.

The different projects are described as:

- **Research center** conceived as a demonstration building (Energy Efficiency Center ZAE Bayern)
- **Applied research center** for development, testing and demonstration (Fraunhofer InHaus Center)
- **Showcase home** for innovative energy efficient energy and retrofitting technologies (City-zen Test Living Lab)
- Standardized **European research infrastructure** for researching human interaction with the home (Living Lab.)
- **Experimental Plus-Energy Student Residence** (Cubity)
- **Off-campus design-build program** (Rural Studio)
- Large-scale **construction facility** for experimental building activities (Les Grands Ateliers)
- **University building as a showcase** for refurbishment with aspects of energy efficiency, including research on user-building interaction and user engagement (Living Lab IESD)
- Solar house as **residence building** within a strategic development for research and teaching on solar architecture and technologies (Show Me House – Solar Village)
- Energy-positive or "Plus energy" home as a **showcase home** within a campus space for experimental prototypes (SurPLUShome – Solar Lichtwiese)
- Energy self-sufficient solar house as **research laboratory** in the context of an open innovation campus ecosystem (Magic Box – Campus Montegancedo)
- Solar house as **Living Lab for research and teaching** of energy efficient architecture (home+)
- Solar house as an **office and demonstration building**, and occasionally housing (Mobile Utility Unit – CMPBS)
- Solar house as a **solar powered showcase home** and interpretative center (Interlock house)
- Solar house as an **experimental platform for teaching and learning** about sustainable architecture, sustainable lifestyle and ESD (Living Lab LOW3)
- Solar house as **community building lab** and place for meeting and organizing neighborhood initiatives (Pas a Pas)
- Solar house as a **neighborhood co-housing facility** for meeting and organizing neighborhood initiatives (Ressò)
- Low impact **prototype home as showcase** and for evaluation under real conditions of use (LIMA)
- Sustainable **prototype home for user-centered research** (Prototype 1 – Concept House Village)
- Apartment as multi-disciplinary **observational research facility** (PlaceLab - House_n)

Objectives and research focus

In the following the different objectives of the presented case studies are listed in order to offer an overview of the **wide range of declared objectives and specific research focuses** given for each project:

- To **create a reference building**, implementing innovative techniques, for research and demonstrational purposes (Energy Efficiency Center ZAE Bayern)
- To **develop, test and demonstrate new solutions** for rooms and buildings and bring them to the market (Fraunhofer InHaus Center)
- To **display and test innovative solutions** for buildings (City-zen Test Living Lab)
- To contribute to the **realization of more sustainable households** in Europe (Living Lab.)
- To **foster research and experimentation** regarding living space for students (Cubity)
- To give architecture students a more hands-on **educational experience** attending at the same time an underserved population (Rural Studio)
- To **offer a platform for experimentation, co-creation and innovation** of construction systems, and prototype buildings (Les Grands Ateliers)
- To **be a resource for teaching and research** into sustainability for buildings, energy and behavioral changes (Living Lab IESD)
- To **allow users a personal living experience** in an energy self-sufficient solar house (Show Me House – Solar Village)
- To **showcase** a Plus Energy Solar house and spread related knowledge and concepts (SurPLUShome – Solar Lichtwiese)
- To **offer a multidisciplinary laboratory for research and training** on sustainable buildings, renewable distributed generation and intelligent control (Magic Box – Campus Montegancedo)
- To **carry out technological research** on energy efficient architecture, renewable energy and innovative HVAC concepts for buildings (home+)
- To **offer education, research, and demonstration** in the field of sustainable building design (Mobile Utility Unit – CMPBS)
- To **establish a residential community laboratory** aimed at optimizing energy efficiency through design tools and strategies (Interlock house)
- To **establish a platform for collaborative and participatory learning** activities regarding ESD in general with focus on sustainable architecture and lifestyle (Living Lab LOW3)
- To **establish and support neighborhood initiatives** in the field of energetic refurbishment and general improvement of housing and community spaces (Pas a Pas)
- To **create a neighborhood facility** for a low-density neighborhood in order to foster knowledge and community action in the field of energy efficiency, renewable energies, sustainable lifestyles and social innovations. (Ressò)
- To **carry out performance evaluation** under Mediterranean climatic conditions in order create knowledge for a new low impact construction standard (LIMA)
- To facilitate a place where innovative, green, attractive living **concepts can be demonstrated and tested** for future large-scale production (Prototype 1 – Concept House Village)
- To **develop innovative user interface applications** that help people control their environment, save resources, remain mentally and physically active, and stay healthy through sensors installed in a home. (PlaceLab - House_n)

Users

In the following, the different user groups of the case studies presented are listed in order to offer an overview of the wide range of users, who participate in or benefit from each of the presented projects:

- Employees, collaborators and partners (Energy Efficiency Center ZAE Bayern)
- Researchers, experts and companies (Fraunhofer InHaus Center)
- Neighbors of the city district and also external visitors (City-zen Test Living Lab)
- European research community together with collaborating companies. (Living Lab.)
- Members of the academic community, students and researchers (Cubity)
- Students and faculties who work within the communities, together with clients or "end users" of the projects who will live in them (Rural Studio)
- Students, faculties, professionals, researchers and companies (Les Grands Ateliers)
- Members of the academic community, carrying out research and innovation projects with the participation of students, administration and private companies (Living Lab IESD)
- Mainly undergraduate students who live in the houses, researchers and the general public (Show Me House – Solar Village)
- The academic community and visitors (SurPLUShome – Solar Lichtwiese)
- The academic community together with collaborating companies and visitors (Magic Box – Campus Montegancedo)
- Members of the academic community and visitors of the prototype (home+)
- Students, faculties and visitors to the center (Mobile Utility Unit – CMPBS)
- Office employees, researchers, students and visitors (Interlock house)
- Members of the academic community and visitors (Living Lab LOW3)
- Neighbors of the community (Pas a Pas)
- Members of the local community (Ressò)
- Academic community, collaborating companies, visitors and office employees. (LIMA)
- Consortium members, academic community and general public (Prototype 1 – Concept House Village)
- Researchers and collaborating stakeholders including companies (PlaceLab - House_n)

User involvement in innovation processes

Different degrees of user involvement can be observed, with the following distribution:

- **Users as visitors**: All projects are open for educational visits
- **Users as observed subjects**: All projects (with exception of SurPLUShome, Magic Box, home+, Pas a Pas, Ressò and LIMA) are evaluating data from users through user observation, user surveys, user interviews or similar techniques.
- **Users as participating subjects**: In all projects (with exception of City-zen Test Living Lab) users, which can be tenants, researchers, workers, students, neighbors or visitors, are actively participating in innovation activities together with a larger group of stakeholders.

- **Users as drivers**: Only a few projects give the user the role of a driver of innovation. Nevertheless must be remembered that the "user" refers to the user of the Living Lab infrastructure, and therefore does not only refer to a so-called "mainstream user" of a product or service but to other profiles of users. Energy Efficiency Center ZAE Bayern, Fraunhofer InHaus Center and LIMA do have researchers and professionals as users, who naturally enroll in innovation activities within their environment. Living Lab LOW3 inspires academic users to be drivers of innovation projects. Pas a Pas and Ressò are community labs, which intend to give the active role to members of a neighborhood in order to start innovation initiatives.

Open Innovation

Open innovation processes refer to externalization of innovation activities or collaboration with external experts, mostly based on economic and IPR agreements. Open innovation processes are included in the following projects:

- Fraunhofer InHaus Center: collaborates with other Fraunhofer Institutes as stakeholders in **shared innovation** projects.
- Energy Efficiency Center ZAE Bayern: contracts **external collaborations** according to research projects.
- PlaceLab - House_n: opens its infrastructure to external research projects as an **innovation service.**
- Pas a Pas and Ressò: these projects might have the capacity to generate open innovation regarding **social innovation** projects, externalizing innovation tasks e.g. to university or external experts. This type of open innovation might not be dominated by economic or IP interests, but is based instead on voluntary involvement and social commitment.

Real-life environment

All projects are situated in a **real-life environment** in order to drive context related innovation processes, testing and evaluation under real conditions of use. Nevertheless some projects partially have the character of research infrastructure and are not settled in their typical environment, such as a housing area of a city, but are, for example, in specific city development zones (Prototype 1), attached to research infrastructures (Fraunhofer InHaus Center) or at university campuses (SurPLUShome, Magic Box, home+, Living Lab LOW3)

In addition some projects **simulate real-life environments** for applied research (Energy Efficiency Center ZAE Bayern, Fraunhofer InHaus Center) for testing and innovation e.g. of specific technological solutions.

Outcomes

Regarding outcomes, all projects are focused on **research and education,** based on their link to higher education institutions or through general knowledge dissemination.
Two projects are additionally **market oriented** and focus on products and service development for companies (Energy Efficiency Center ZAE Bayern, Fraunhofer InHaus Center, and Prototype.1).
Some are specifically focused on **social innovation** processes and action-based innovation (Rural Studio, Pas a Pas and Ressò)

Organizational structure and lifespan

Many initiatives are based on specific research projects, e.g. the Solar Decathlon prototype developments, and have initially a **limited organizational continuity and lifespan**, due to their project characteristics, objectives and financial resources. Nevertheless they can evolve over time into more or less consolidated infrastructures with their corresponding program of activities (e.g. SurPLUShome, Magic Box, home+, Interlock house, Living Lab LOW3, Pas a Pas, Ressò).
Others are based on and embedded in **consolidated organizational structures** of for example research institutes or universities and are meant to be **continuous initiatives** (e.g. Energy Efficiency Center ZAE Bayern, Fraunhofer InHaus Center, Les Grands Ateliers, Cubity and Prototype 1).
According to the individual circumstances of each project these conditions can change and projects can terminate e.g. due to organizational changes, technological obsolesce or changes in related research paradigms (e.g. PlaceLab).

Comments by project leaders

Online questionnaires and personal interviews have been carried out with the project leaders of the majority of the projects in order to obtain first hand feedback and updated data about the individual initiatives.
Regarding the difficulty in obtaining real monitoring data of buildings and real conditions of use, and specifically the post-competition use of Solar Decathlon prototype buildings within structured research and teaching, the project leader of the Interlock House (SD 2009) project from Iowa State University, Ulrike Passe, states:
“We have probably one of the best monitored solar homes of all the US Solar Decathlon homes, but it all took a long time to mature and it is still not running optimal, but we are getting there.”[108]
Some leaders summarize the strength of their projects as the following:
“It is a unique interdisciplinary learning platform on our campus” (home+)
All interviews served to contrast publicly available information and to gather additional feedback about the actual situation of projects.

[108] Citation of Prof. Ulrike Passe (Iowa State University), online questionnaire on Living Labs, Sept. 2014

Summary and Conclusion

This section has described 20 relevant *Living Lab-like* infrastructures or *architecture laboratories* for research and innovation linked to universities or in close contact to higher education teaching and research activities..
Detailed information has been given over their main constituting parameters including stakeholders, objectives, concept, facilities and tools, users and their role, projects and activities as well as outcomes. Their approach to multidiscplinarity, the type of user involvement, and the application of co-creation and (open) innovation approaches have also been discussed.

It shows that a great variety of concepts exists, which are reflected in the diversity of descriptions for individual projects such as **research center, applied research center, showcase home, European research infrastructure, experimental plus-energy student residence, off-campus design-build program, construction facility, university building as showcase, residence building, research laboratory, living lab for research and teaching, office and demonstration building, solar powered showcase home, experimental platform for teaching and learning, community building lab, neighborhood co-housing facility, prototype home as showcase, prototype home for user-centered research, observational research facility.**

Objectives and research focus are correspondingly diverse, including descriptions like: **to create a reference building, to develop, test and demonstrate new solutions, to foster research and experimentation to contribute to the realization of more sustainable households, to offer a platform for experimentation, co-creation and innovation, to be a resource for teaching and research, to allow users a personal living experience, to showcase, to offer a multidisciplinary laboratory for research and training, to carry out technological research, to establish a residential community laboratory, to establish a platform for collaborative and participatory learning, to establish and support neighborhood initiatives, to carry out performance evaluation or to develop innovative user interface applications.**

User groups can consist of **visitors, citizens, employees, collaborators, researchers, students, faculties, professionals, experts, companies, and community member of the city district.**

Different **degrees of user involvement** may be observed, **users as visitors, users as observed subjects, users as participating subjects** or **users as drivers of innovation processes.**

Different **types and degrees of open innovation** may be detected in projects, with different approaches including **shared innovation, external collaborations, innovation services** and **open social innovation**.

Outcomes may be divided into the basic categories of **research and education focused activities, market oriented products and service development,** and **social innovations.**

Regarding **organizational structure and lifespan,** projects may be divided into those with **limited organizational continuity and lifespan**, and other more continuous projects **based on consolidated organizational structures.**

The 20 recent case studies presented show the existing **diversity of approaches** to innovation through Architecture Living Labs, based on user-centered research in real-life environments with a pluridisciplinary view and a collaborative and co-creative approach to innovation.

4.4 Conclusions

This chapter has focused on the holistic understanding of the development of architecture laboratories and prototypes of the 20th and beginning of the 21st century related to solar energy and sustainability and leading towards the recent phenomena of Living Labs in Architecture.

Buildings today are increasingly optimized and better understood in their complexity regarding resource consumption, environmental impact and their relation to lifestyle, as well as their role as part of complex systems and environments, physically, socially, energetically and environmentally spoken.

The role of the user has gained increasing importance and its relation and interaction with technological systems and the whole building is focused through so-called user-centered research and innovation.

Throughout the 20th century a development can be observed from observational laboratories to Living Labs with a strong connection between education, research and innovation. The development of sensor technologies and data collection has increasingly allowed the use of monitoring devices and improved observational tools for user-centered research and the capturing of user insights and behavior.

Recent Living Labs are open innovation ecosystems which change and adapt over time to new market trends, consumer demands and behaviors, social and environmental challenges as well as technological innovations in order to maintain their validity and strength for being effective and useful infrastructures in the field of research and innovation.

Understanding the historical development and recent concepts of Architecture Living Labs, allows discovering their potential within the holistic transformation process of society towards sustainable development and possible synergies between research, innovation and education across the field.

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5 LIVING LABS IN ARCHITECTURE FOR ESD IN HIGHER EDUCATION

Highlighted the principles of Education for Sustainable Development (ESD) on one side (Chapter 2), and the conceptual framework of Living Labs in general, with the specific concept of Living Labs in Architecture, on the other side (Chapter 3), focus of this chapter is to analyze the role of Architecture Living Labs in Higher Education Environments regarding Education for Sustainable Development (ESD). This will be done based on analyzed historical and recent case studies (Chapter 4) and through a detailed comparison of the different concepts, methodologies and approaches which characterize Living Labs on one hand and Education for Sustainable Development on the other.

5.1 Introduction

Narrowing down the generic field of Living Labs to the discipline of Architecture, we can define an important field of research and innovation, which is widely promoted by politics, institutions and civil society, as well as an important field of activity for private companies and a research field in higher education: **Sustainability related to our built environment, housing and lifestyle**.

As shown in chapter 2.4, **education in the field of sustainability** and specifically **ESD** requires the definition of a whole set of **new learning outcomes**, which can be achieved best through specific **learning environments, tools and methods**, fostering **ESD related knowledge, skills and competences** and offering space for **personal and collective definition of values**. Living Labs in Architecture, related to Higher Education Institutions (HEI's) might match this demand for new learning environments and methods, which offer specific qualities for ESD related teaching and learning activities.

In this sense, Living Labs in Architecture, besides being an efficient **tool or methodology** for crossing the "pre-commercial gap" of innovations (European Commission 2009), might be **forerunners** for a new and innovative way of **sustainability related teaching and learning** at universities, strongly linked to **collaboration, co-creation and innovation in real-life contexts**.

Architecture Living Labs related to teaching and learning in HEIs

Prototype architecture and architectural laboratories have a long tradition in the history of Architecture and a strong relationship to the research and educational sector. Chapter 4.2 shows some of the best-known examples of historical pilot buildings and laboratories developed and built by higher education institutions, for example the **MIT solar house program** of the 1940's and 1950's (case studies H03, H06 and H08). In recent years the **Solar Decathlon**

Competition has become a powerful concept for involving universities again in the **design and construction of prototype solar houses** (case study H25), a strong approach that generated a series of **Living Lab like initiatives** (case studies R09 - R17), based on competition prototype buildings and sited at university campuses or the immediate social context of universities.
Based on the general, **"innovations-for-market"** oriented definition of Living Labs, a proposal is made to translate the Living Lab concept to the field of architecture, with a specific focus on higher education environments and their potential contributions to teaching and learning about sustainable architecture, sustainable lifestyle and sustainable development in general.

5.2 Architecture Living Labs for ESD in HE – framework proposal

According to European Network of Living Labs (ENoLL)[109], "*a Living Lab is a real-life test and experimentation environment where users and producers co-create innovations", with* four main activities typically employed by Living Labs:

- **Co-Creation**: co-design by users and producers
- **Exploration**: discovering emerging usages, behaviors and market opportunities
- **Experimentation**: implementing live scenarios within communities of users
- **Evaluation**: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria.

On the other hand, as stated in chapter 3, the main constituting characteristics of Living Labs have been identified as the following:

- **Multi stakeholder approach**: often based on a PPP (Public-Private-Partnership)
- **User involvement**: giving a special role to the user as part of the innovation process
- **Open Innovation**: considering innovation as an open process with multiple stakeholders
- **Real-life environment**: experimenting and capturing user insights in real-life contexts

Understanding these 4 principals activities and these 4 constituting characteristics as a framework for the definition, operation and management of Living Labs, a closer look will now be made on **Architecture Living Labs in HE, focused on ESD**, in order to discover synergies and identify possible common strategies and concepts of Living Labs and ESD.
This approach will be discussed for Living Labs in Architecture but could also be considered for Living Labs in other academic disciplines.

5.2.1 HE Living Lab Ecosystems

A general typological framework for Living Labs regarding their places and functions within HE is represented graphically in Figure 5.1. Considering that the traditional fields of activity in Higher Education Institutions are divided into Teaching, Research and *Innovation and Outreach*[110], **Education for Sustainable Development** activities are located in the field of Teaching as a supplement to traditional disciplinary educational practices (or somehow integrated and

[109] http://enoll.org
[110] referring to all interaction with society beyond HE Teaching and Research, like e.g. Technology Transfer, Societal Outreach or Community Services, contributing to societal development

merged with them, which is an on-going discussion), and are also linked to the fields of Research and Innovation and Outreach.
Living Labs appear at the **cross-section of all areas**, giving place to research focused, innovation and outreach focused, and education focused Living Labs, or located at the center point of all three areas, to **ESD focused Living Labs.**

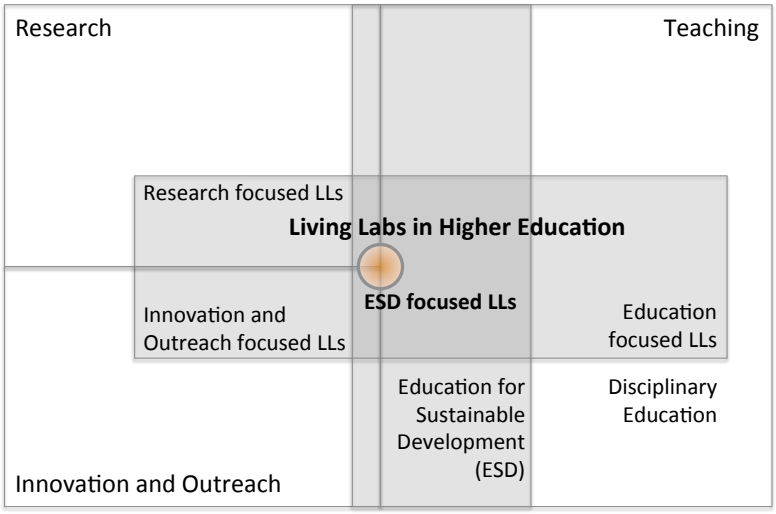


Figure 5.1 Framework of Living Labs in Higher Education – *HE Living Lab Ecosystem*

All these forms of **HE Living Labs** generally have a set of stakeholders behind them, consisting of industry, administration or society based partners, constituting different forms of Public Private (PPP) or even **Public Private People Partnerships (PPPP)** as described in chapter 3.
This opens up diverse Living Lab initiatives in HE towards society and allows for example, integrating the **ESD component of academic Living Labs** into life-long-learning activities in its societal context, creating synergies and building up a **Higher Education Living Lab Ecosystem.**

5.2.2 Living Labs as part of Holistic SD Transition Arenas in HE

Nevertheless according to the analyzed Living Lab framework (chapter 3) and the specific case studies discussed in chapter 4, a continuous transition between teaching, research and innovation and outreach activities can be assumed for most Living Labs, and many initiatives have a strong link to all three areas, with **SD and ESD as common paradigms**.

On the other hand the classical sectors of **disciplinary education, traditional science** and **traditional societal development** are undergoing intense transformation processes at all levels towards SD.

Within the Research sector, **Sustainability Science** (chapter 2.4.1) is defining a new way of understanding and conducting research, and in the Educational sector disciplinary education merges increasingly with **ESD**; in the Innovation and Outreach sector, traditional understanding of societal development gets increasingly transformed towards the paradigm of **Sustainable Development**.

Fig.5.2 represent this transition processes graphically, with limits blurring between traditional and sustainable approaches in each sector, as activities in HE focus more and more on paradigms for a transition towards sustainable development.

Overcoming these sectorial limits and the merger towards the complementing sectors, allows an activity or project to form part of a **Holistic SD Transition Arena**[111] of its HEI.

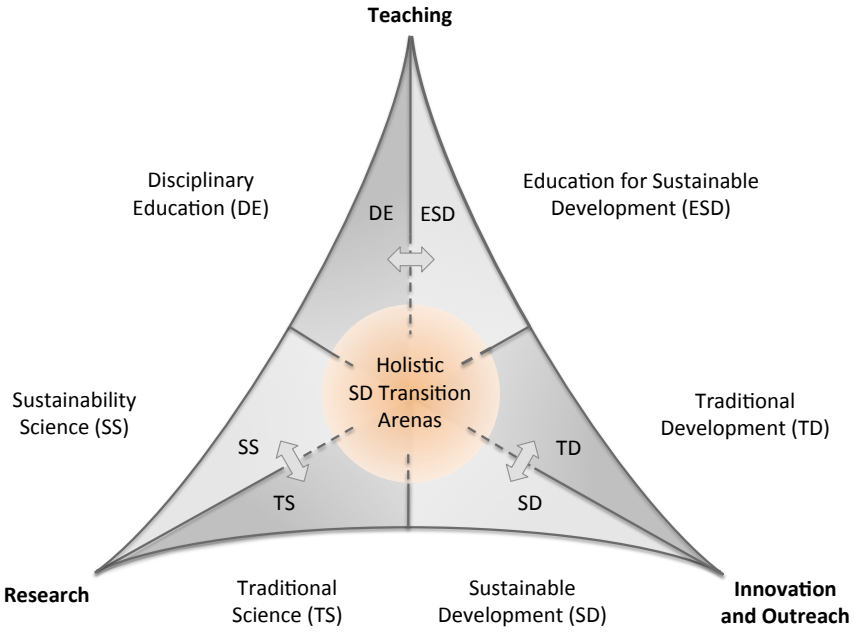


Figure 5.2 Transition of Higher Education towards SD – *Holistic SD Transition Arenas*

Transition arenas can be defined as an informal network of frontrunners, which engage in creative group processes in order to detect needs and opportunities for systemic changes, developing innovations for corresponding transition processes. They operate in experimental and only minimally regulated spaces in order to develop **innovative ideas and concepts** (Loorbach & Rotmans 2010).

Translated to HE, transition arenas might be defined as places, projects or networks of people, who **collectively innovate** for transition processes within their institutions and beyond.

ESD focused Living Labs in HE form part of these arenas among other activities, projects or initiatives in HE; together they contribute to the creation of a step-by-step *momentum* for a holistic transition of HEIs towards SD.

[111] The idea for this graphic representation of transformation processes in HE towards SD and ESD arose from a fruitful conversation with Prof. Arnim Wiek from Arizona State University, expert in transformational learning, during his visit to UPC in September 2015, discussing the idea of Living Lab Ecosystems as presented in chapter 5.2.1.

5.2.3 The concept of Architecture Living Lab in HE

Once highlighted, the general framework of Living Labs in HE and their specific role regarding SD and ESD, principal **Living Lab descriptors** are listed in Table 5.2 with their definition according to the generic Living Lab approach and an interpretation for the specific Architecture Living Lab approach in HE environments based on the case study analysis of chapter 4.

This allows discussing later on **communalities** between Living Lab activities, ESD related skills and competences, and pedagogical strategies in the discipline of Architecture.

Descriptors	**Generic Living Lab approach**	**Architecture Living Labs in Higher Education Environments**
Living Lab	Platforms which involve users in the innovation process by designing, developing and validating new technologies, products and services within real life environments" (Almirall, 2008, p.22).	Architecture Living Labs are settled at the intersection of Living Labs on one side and Prototype Architecture and Architecture Laboratories on the other side
Real-life environment	Any real-life setting as in public administration facilities, offices, housing, public space, hospitals or 1:1 prototype infrastructures.	Campus areas, campus buildings, prototype buildings or outreach projects close to the campus within the societal context of university.
Test and experimentation	Implementation of new products, service, technologies or ICT solutions into real working or living environments with evaluation under real conditions of use through users.	Implementation of new technology or ICT solutions into real HE working environments with evaluation under real conditions of use. Experimentation of new forms of housing, living, working and lifestyle through prototyping and *living labbing* e.g. at faculties of Architecture.
Main drivers	Companies and Research Institutes or public institutions.	Universities and related Research Institutes together with companies, public institutions or social entities.
Users	Users within their real-life environment: employees, citizens, patients, workers and similar collectives.	Academic community (students, researchers, administrative staff), companies, external participants or visitors.
Producers	*Users as producers* together with companies and researchers developing a market-oriented product or service idea.	Academic community (students, researchers, administrative staff), in the role of co-producers of innovations.
Co-creation	Co-creation of knowledge, ideas, concepts and innovations between companies, researchers and users.	Co-creation of knowledge, ideas, concepts and innovations between students, researchers, companies and other participants (professionals in the building sector, administration, citizens).

Innovation	Generation of new or improved products or services focused on the market.	Broad and exploratory approach to the generation of new or improved concepts for products, services or initiatives often related to the HEI and its own pathway to SD.
User-driven innovation	Employees or citizens as users evaluate a product or service and contribute to the innovation process driven by other stakeholders (companies, researchers, experts).	Students, researchers and participants in general as users evaluate a product, service or concept and generate innovations together with other stakeholders.
Open Innovation	Innovation process through collaboration with external agents like companies, research institutes or other experts. Market driven, IPR oriented and based on economic interest.	Innovation process through collaboration among university stakeholders (students, researchers, teachers, administration) together with companies, research institutes, citizens. Often focused on social innovation rather than market-oriented.
Public Private Partnership (PPP)	Different stakeholder combinations (see chapter 3.2.6)	No differences to the general LL approach. Alternatively: internal partnership within academic community or among HEIs.
Outcomes	User insights on usability, user acceptance and market viability, e.g. for marketing purposes on any product or service, which can be tested by users. Innovation ideas for development towards market-readiness.	Prototype solutions and knowledge generation (usability, comfort, user experience) in the fields of sustainable building concepts, energy efficiency, sustainable lifestyle, sustainable consumption or behavior change models contributing to technological or social innovations.

Table 5.1: Descriptors for the generic Living Lab approach and for Architecture Living Labs

This shows that all used generic descriptors of Living Labs do have a slightly different definition according to the setting of a Living Lab within Higher Education Institutions in the field of Architecture and with a focus on ESD. Nevertheless many of the descriptors can be translated to the HE environment and related to **ESD teaching and learning practices**.

The **main results** of the interpretation of Living Lab descriptors specifically for Architecture Living Labs in HE environments can be stated as following:

- The **real-life environment** of HE Living Labs is represented through the local context of university, e.g. the own campus, or the immediate societal context.
- **Test and Experimentation** are mainly carried out within this context, related to university buildings, prototype buildings or application laboratories at faculties of Architecture.
- **Main drivers** are HEIs themselves, with a broad focus on teaching, research and innovation.
- **Users** are mainly the academic community, with students and researchers as main drivers of Living Lab initiatives.

- **Focus** is generally less market-driven, but focused on services or initiatives related to the HEI and its pathway to SD or to social innovation processes in the immediate societal context.
- **Processes of innovation** are broader and exploratory, and not so much outcome or market oriented.
- **Open innovation** processes are less market-oriented and IP dominated, but generically open to other stakeholders, without economic interests behind and more focused on social than on technological innovations.
- **Outcomes** are often new knowledge and ideas, which contribute to personal and professional development of participants, and less to market ready products or services.

The main similarities between a general Living Lab approach and the specific Architecture Living Lab approach in HE will be discussed in the following part, describing specific **ESD related competences and strategies** which can be related to the specific concepts and activities.

5.3 Communalities: Architecture Living Lab vs. ESD

In order to develop important synergies between Living Lab initiatives and ESD activities in HE environments, it is relevant to detect and foster the communalities between both approaches. In the following part, basic Living Lab principles are related to ESD competences and strategies through specific proposals of activities of Architecture Living Labs in HE.

5.3.1 ESD and the multi stakeholder concept of Living Labs

Diversity of stakeholders is a main characteristic of the Living Lab approach. Corresponding Living Lab specific approaches can be related to ESD competences and strategies through the following examples of Living Lab activities:

Concept 2: Multi stakeholder participation		
Living Lab approaches	**Architecture Living Labs in HE Activities**	**Related ESD competences and strategies**
Multi stakeholder process	Transdisciplinary approach, e.g. university, industry, professional institutions and public institutions collaborating for research and innovation regarding nearly Zero Energy Buildings as future building standards.	Anticipatory competence, system thinking, normative competence, interpersonal competence: ***cooperation in a research team***
Pluridisciplinary mix of stakeholders	Involvement of different departments and disciplines, e.g. regarding sustainable housing and lifestyle concepts from a social, economic, technological and environmental point of view.	Transdisciplinary thinking, normative competence, interpersonal competence: ***cooperating beyond the own discipline***
Public Private Partnership (PPP)	Academic community as stakeholder (internal partnership) or university-society-industry partnerships (external partnerships)	Values and ethics: ***commitment to societal progress and well-being***
Social dynamics of Living Labs	Stakeholder diversity regarding disciplines levels of knowledge, age, background, values e.g. within a community outreach project	Interpersonal competence, negotiation skills, empathy: ***being empathic and tolerant to others***

Table 5.2 Relation between ESD and the multi stakeholder approach of Living Labs

Stakeholders of academic Living Lab facilities

Within the academic environment of higher education institutions, and specifically in the field of Schools of Architecture, the stakeholders of Living Lab infrastructures can be diverse:

- *Students:* participating in Living Lab activities linked to teaching or as collaborators in research and innovation activities
- *Individual Researchers:* using the Living Lab infrastructure as place for carrying out a research project and connecting to others
- *The academic staff in general:* using the Living Lab as co-creation place for innovation in teaching methods and transversal knowledge source regarding sustainability
- *The institutional leaders and administration:* using Living Labs as places of co-creation of ideas about optimizing institutional mechanisms and patterns (energy saving, participation processes, resource efficiency, crowdsourcing of innovative ideas in general)
- *Local authorities*: externalizing idea generation and participative processes for innovation to existing Living Lab facilities at their local university
- *Citizens:* Participating and benefiting from Living Lab activities in the field of education, according to a life-long-learning approach of society

5.3.2 ESD and the user involvement concept of Living Labs

User involvement is an important concept in Living Labs. Corresponding Living Lab specific approaches can be related to ESD competences and strategies through the following examples of Living Lab activities:

Concept 2: User involvement		
Living Lab approaches	**Architecture Living Labs in HE activities**	**ESD competences and strategies**
User exploration and testing	Experience based learning, e.g. *testing and evaluation of the energetic performance of a prototype solar house* or testing of a new product or service related to a low-carbon lifestyle	Critical thinking, Experience based learning, team working, learning-by-doing: ***explorative learning approach***
User centered research	Student-centered learning, e.g. *evaluation of a prototype building under real conditions of use*, focusing e.g. on user behavior and user building interaction	Problem based learning, team working, leadership: ***human-centered research and understanding***
User co-creation	Participatory teaching and learning, e.g. *co-creation of conceptual or technological innovations* of existing buildings, products, systems or services	Active learning, problem based learning, interpersonal competence: ***co-creation of knowledge and understanding***
User driven processes	Student as leaders of own projects, e.g. *bottom-up initiatives and development of social innovation projects*, inspired and supported and hosted by a Living Lab	Project based learning, system thinking, critical thinking: ***students as drivers and leaders of initiatives***

Table 5.3 Relation between ESD and the user involvement approach of Living Labs

Academic Living Labs can adopt a **special role** between the public and the private sector, bringing together players of each branch in order to install **participatory processes** of innovation in technical, economic, social and environmental issues. This allows the creation of common platforms that can be used jointly and where synergies can be discovered and fostered as well as important processes like **common vision building** or **road mapping, which** can take place in order to start **complex multi-stakeholder processes** for change towards a more sustainable society.

Academic Living Labs can adopt the function of **incubators for societal outreach** regarding knowledge dissemination and the approach to societal challenges, generating projects and collaborations, which strengthen the role of university as an important agent for change in society.

It shows that Living Lab activities, related to user involvement and evaluation of user behavior have a strong relation to pedagogical strategies related to ESD.

5.3.3 ESD and the open innovation concept of Living Labs

Open innovation is another basic concept related to Living Labs. Corresponding Living Lab specific approaches can be related to ESD competences and strategies through the following examples of Living Lab activities:

Concept 3: Open Innovation		
Living Lab approaches	**Architecture Living Labs in HE activities**	**ESD competences and strategies**
Open Innovation approach	Creative, participatory open activities, e.g. *open innovation sessions* with public entities, public institutions, citizens and experts regarding social innovation initiatives, urban development, public space or any other community relevant issue in the local context	System thinking, normative competence, interpersonal competence, problem based learning: ***collaboration in open innovation sessions***
External collaborations in innovation	Structured collaboration processes e.g. in the field of resource efficient, sustainable and affordable housing through *innovation service contracting* offered to companies or public administration	Anticipatory competence, system thinking, normative competence, interpersonal competence: ***cooperation in an open innovation project***

Table 5.4 Relation between ESD and the open innovation approach of Living Labs

Open Innovation strategies, focused on collectively generating and sharing innovation, fit well into the Living Lab approach. Open innovation can have two interpretations in the context of academic Living Labs. One approach would be the organization or participation in social innovation initiatives in the local context, as open and **non-profit commitment with society**.

The other approach focuses on **innovation service contracting** between university and companies or public administration, including agreements regarding Intellectual Property Rights. Both options offer interesting opportunities for ESD activities, fostering related competences.

5.3.4 ESD and the real-life setting concept of Living Labs

Real-life setting is an important characteristic of Living Labs. Corresponding Living Lab specific approaches can be related to ESD competences and strategies through the following examples of Living Lab activities:

Concept 4: Real-life setting		
Living Lab approaches	**Architecture Living Labs in HE activities**	**ESD competences and strategies**
Real-life setting	HEIs' environments (prototype buildings, campus buildings or spaces, campus as a whole) can be *set up as Living Labs for experimentation* by students	Critical thinking, Experience based learning, Knowledge for action: ***collaboration in a campus research team***
Context relation	The immediate social environment of HEIs can be activated and used for context related research and innovation e.g. through *community action projects* driven by students and researchers, which include a Living Labs infrastructure	Solving real-life challenges of society, Experience based learning, Knowledge for action: ***cooperation in a societal innovation project***

Table 5.5 Relation between ESD and the real-life setting approach of Living Labs

Living Labs can facilitate the **connection to real-life context** and related SD challenges of society for their integration in ESD activities, generating knowledge for action, and gaining insight in societal realities through access to large user groups and societal stakeholders.

5.3.5 Conclusions

Settling a Living Lab in the academic environment of a HEI can contribute to the institutional transformation towards SD at all levels.
Considering the specific conditions of HEI's as social community of several thousand members, large infrastructures and a considerable operational impact, **university or campus living labs** could serve as physical and/or virtual platforms for collective innovation regarding a holistic transition towards SD of the HEI as a whole, e.g. through the co-creation and evaluation of corresponding transition management strategies. Possible stakeholders can be students, the HEI management, researchers, maintenance personal, companies, university spin offs or start-ups. Living Labs can serve as **transformational tools for HEI's transition towards SD.**

5.4 Common conceptual framework of ESD and Living Labs

Approaching a common framework of ESD and the Living Lab approach from the ESD side, the following 4 paradigms have been identified as characteristic for ESD, and can be related to corresponding Living Lab concepts as following:

1. Pluridisciplinary Systemic Approach (People)

ESD is based on a critical **transdisciplinary and systemic view on sustainability** related to our production and consumption systems, lifestyles and their environmental and social impact.
SD is a **multi-stakeholder process**, which needs to integrate all relevant actors of society.

Corresponding Living Labs concepts: multi stakeholder process, pluridisciplinary and transversal, PPP.

2. Participatory Co-creative Action (Process)

SD is a process, which is **open ended**, dealing with uncertainty and adaptation according to new knowledge and with changing paradigms as part of the process.
Pathways for changes towards SD must be **generated, negotiated and agreed by society** and are related to the **generation of new values,** which must be **defined, and adopted collectively** by participants in the process in order to make related transformation process effective and long lasting.

Corresponding Living Labs concepts: User involvement, user co-creation, participative process.

3. Open Collaborative Environment (Attitude)

ESD is about **exploration, insight, understanding, co-creation, adoption and implementation** of more sustainable solutions as answers to societal SD challenges. The **process of ESD itself is transformative** and should be based on the **free availability and interchange of knowledge** (knowledge as common good, not an economic value), as well as **collaboration and trust** among persons (e.g. in the discussion of values).

Corresponding Living Labs concepts: Open Innovation, collaboration among entities, networking and the interchange of knowledge among partners.

4. Real-Life, Context-related Settings (Context)

ESD must be **related to real problems in its real contexts**, in order to search for systemic solutions, considering all relevant social, environmental and economic aspects, not limited to disciplinary short-term changes. **Knowledge for action**, paradigm of sustainability science, is a key element of ESD and requires relation to real-world challenges.

Corresponding Living Labs concepts: Real-life environment – people in their everyday life, context related, multi-faceted.

Fig.5.3 represents how the 4 described paradigms together constitute a **common conceptual framework** for activities in the field of Education for Sustainable Development (ESD) and the Living Lab approach to innovation.

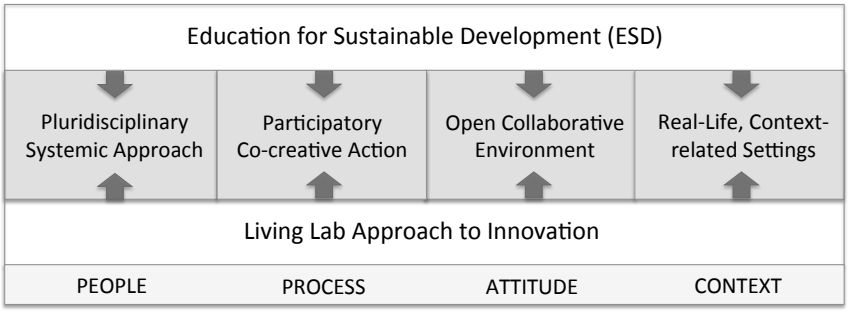


Figure 5.3 Common conceptual framework of ESD and the Living Lab approach

As a practical application of the identified framework, **Living Lab initiatives** can design ESD related activities based on these 4 common paradigms and integrate them into their overall

activities concept. **ESD courses** can define educational projects and tasks based on these 4 common paradigms in order to integrate students into Living Lab environments for research and learning.

5.5 Holistic role of Living Labs in Architecture for ESD in HEIs

Main drivers of Living Labs in their generic definition are mainly companies which are interested in accelerating a specific product or service development in order to get to the market after testing as quick as possible, optimizing the product or service in a real-life setting with real users. (Almirall & Wareham 2008)
Within an academic Living Lab, e.g. in the field of architecture, with **university as main driver**, **knowledge generation and experience based learning** through testing and implementation of new solutions with users under real condition might prevail over the pure objective of market-readiness of a product or service. The **campus as experimental field for prototyping** serves generally both: teaching and research on one hand, innovation and industry collaborations for product and service development on the other hand.

A second purpose can be the knowledge generation and prototype application for the **improvement of HEIs campus buildings, infrastructures, services and operation** i.e. regarding energy efficiency, environmental sustainability and SD in general, contributing to a HEIs' transition to SD as an organization, community and societal stakeholder. As an open collaborative platform, they can serve as places for bottom-up initiatives regarding a **holistic transition process** of HEI's towards SD
As a result of these campus specific Living Lab dynamics, teaching, research, experimentation and innovation merge together in order to offer a **holistic, transformational learning experience** to all stakeholders, students, researchers, teachers and employees of a campus.

A third mission of Higher Education Institutions is to generate **outreach to society**, with a positive impact on the social and economic context of university, contributing to solve societal challenges and disseminate the generated knowledge to society.
Outcomes of academic Living Labs might therefore be generally prototype solutions instead of market-ready products or services. They might serve as **transversal innovation platforms** for the academic community of HEIs, with other entities like innovation units, incubators and spin off promotion offices smoothly supporting the further development of ideas and concepts towards the market.

Fig.5.4 represents 3 basic **fields of activity of HEIs as societal actor regarding SD,** with the possibility for Living Labs fulfilling specific internal and external functions and adopting the role as **connecting elements between HEIs and society** in all 3 areas:

HEIs' Teaching, Research and Innovation:
Living Labs can *internally* develop and implement ESD and related teaching and learning strategies, methods and tools in order to promote the integration of SD knowledge, skills and competences in teaching, research and innovation, offering *externally* ESD and SD related R&D services to society.

HEIs' institutional transformation towards SD:
Living Labs can *internally* foster transformation processes towards SD of HEIs as communities with their institutional practices, infrastructures and assessment tools and share *externally* the generated knowledge about SD transition with other entities.

HEIs' societal outreach:
Living Labs can *internally* be places to define and articulate HEIs' outreach to society in order to structure the role of universities as change agents, contributing *externally* to societal processes of transformation towards SD within their local and regional context.

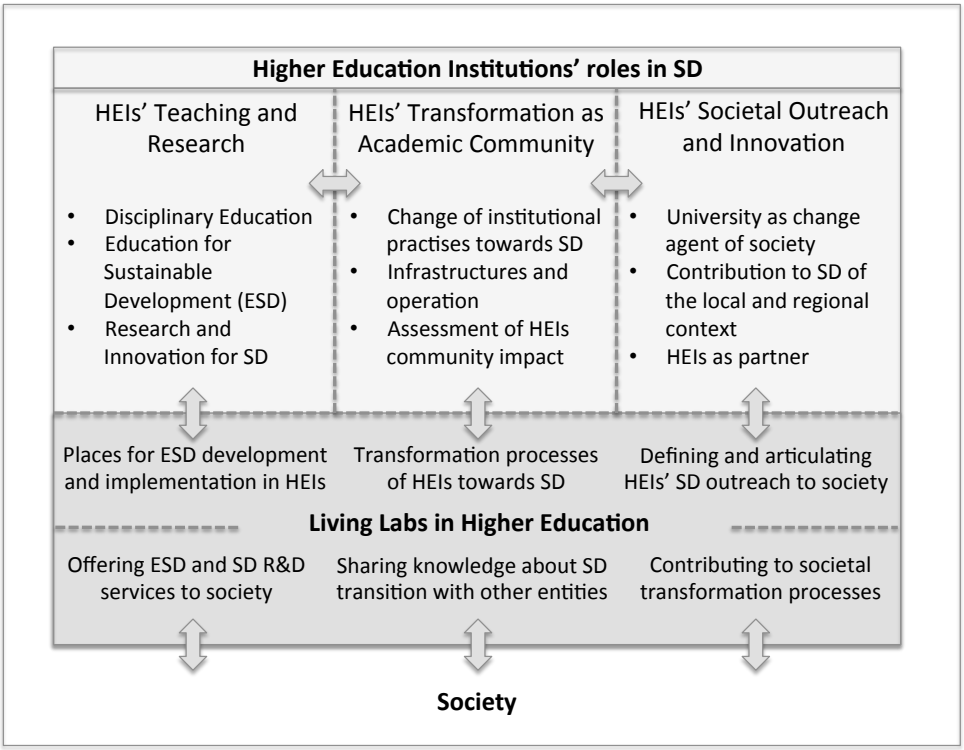


Figure 5.4 Living Labs as connecting elements regarding SD between HEIs and society

ESD in higher education forms part of a **complex transformation process** of the whole higher education systems today. Whereas ESD is mainly focused on a new approaches to teaching and learning, **sustainability science** can be considered the corresponding paradigm for research and innovation.

HEIs' institutional transformation (governance, infrastructures, operation, academic community) and **HEIs' outreach to society** regarding SD are complementing elements for a holistic approach to education for sustainable development.

5.6 Living Lab activities and related ESD strategies and methods

Different key activities are described for Living Labs and related to ESD in order to show how the described common framework can be translated into specific common activities.

5.6.1 Comparison of Living Lab activities and ESD strategies and methods

Divided in 4 basic activity concepts (see chapter 3), specific Living Lab activities are described, identifying corresponding ESD favorable pedagogical strategies and methods as discussed in chapter 2:

Living Lab activities concepts	Specific Living Lab activities	ESD related pedagogical strategies and methods
Co-Creation	Co-design by users and other stakeholders, e.g. of products or services, technological or social innovations Multi stakeholder processes of ideas creation, concept development and prototyping	Problem based learning Project based learning Role play Scenario building Qualitative and quantitative modeling Participatory modeling
Exploration	Discovering emerging usages, behaviors and market opportunities through collective explorative processes	Experience based learning Multi-criteria assessment Scenario building
Experimentation	Implementing live scenarios within communities of users, e.g. usability research, capturing user insights and user feedback, research on behavior change, market viability evaluation	Project based learning Active learning Experience based learning Dealing with uncertainty Risk analysis
Evaluation	Assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria. Holistic analysis of social, economic, environmental and technological aspects.	Multi-criteria assessment Envisioning methods Life-cycle assessment Risk analysis Negotiation Value discussion

Table 5.6 Comparison of Living Lab activities and ESD strategies and methods

It shows that all 4 generic Living Lab activities can be applied in Architecture Living Labs and are in line with ESD strategies and methods for teaching sustainability. This allows the conclusion that Architecture Living Lab activities in HE could serve both purposes: Living Lab research and innovation activities and education for sustainable development.

Regarding key strategies which connect Living Lab activities to ESD, Problem based learning and Project based learning (PBL) are two outstanding educational methods, which can be directly related to Living Lab activities due to their applicability for tackling complex technological, societal or environmental problems and challenges in a holistic, cooperative and creative way.

Also other ESD related educational concepts, methods and strategies are in line with Living Lab activities, e.g. Role play, Scenario building, Qualitative and quantitative modeling, Participatory modeling, Dealing with uncertainty, Multi-criteria assessment, Envisioning methods, Life-cycle

assessment, Risk analysis, Negotiation and Value discussion (from Wiek et al. 2011), but cannot be discussed in detail in this work.

5.6.2 Key strategy 1: Problem based Learning

Problem based learning stimulates a participatory process of knowledge generation, value discussion and solution finding for a specific presented problem. It's a cooperative and active approach to learning
According to Segalàs (2009) the constructivist theory relates to problem based learning in three aspects, which in the following will be correlated to basic principles of the Living Lab approach:

- *The understanding of a situation of the reality appears from the interactions with the surroundings:* **Real-life environments** and context relation of Living Labs facilitate this interaction in multiples ways.
- *The cognitive conflict in facing each new situation stimulates learning:* Living Labs are **Experimental Learning Environments**, which generate constantly new situations and therefor stimulate learning.
- *The knowledge develops through the recognition and acceptance of social processes and of the evaluation of the different individual interpretations of the same phenomenon:* Living Labs are based on **multi stakeholder processes** and pluridisciplinary co-creation activities, which constantly confront participants with societal realities and different interpretations.
  (Segalàs 2009, p. 41)

Due to the described similarities, innovation processes in Living Labs could be designed as Problem based Learning activities in Higher Education, integrating students of a discipline in specific co-creation projects with students from other disciplines (closed academic Living Lab exercise) or with other stakeholders like companies, public administrations, citizens (open academic-societal Living Lab process).

5.6.3 Key strategy 2: Project Based Learning (PBL)

Project Based Learning is a holistic learning method, which encourages students to apply their knowledge, skills and competences in order to cooperatively design and implement a real project. Corresponding learning environments should be open and context related, inspiring and equipped for dynamic group work and discussions.

Basic principles are amongst others:

- Co-creation of a project in an open and creative environment, including value discussions
- Pluridisciplinary approach in order to solve complex challenges
- Projects refer to real-life problems in their specific context

Considering the complexity of sustainability challenges, and the need for a wide, context related scope of projects, the project based learning approach efficiently fosters the collaboration in interdisciplinary teams on complex societal themes and in an integral and creative way (Mulder cited in Segalàs 2009, p. 38).

Principles of PBL match fairly well with Living Lab principles and due to similarities in methods and approach, Living Labs could be the inspiring environments hosting related activities.

5.6.4 Conclusions

Four basic Living Lab activity concepts have been related to corresponding ESD strategies and methods through specific Living Lab activities. It shows that Living Lab research and innovation activities can perfectly match and foster ESD specific competences.
Problem based Learning and Project Based Learning have been discussed as key strategies in Architecture Living Labs for ESD. Both play a strategic role in both concepts, Living Labs and ESD, and therefore are recommendable for application in a common context of teaching, research and innovation.

5.7 Summary and conclusions

In this chapter the role of Architecture Living Labs in Higher Education Environments regarding Education for Sustainable Development (ESD) has been analyzed.

A general **framework for Living Labs in HE** and a corresponding **HE Living Lab Ecosystem** have been described in order to understand the variety of Living Lab typologies related to HE environments and to define the position of **ESD focused Living Labs** within this ecosystem. A corresponding ***Holistic SD Transition Arena*** has been described as a the place where HE traditional disciplinary and new sustainable paradigms merge and activities increasingly focus on a combined teaching, research, as well as innovation and outreach approach. ESD related Architecture Living Labs are identified as

In order to go beyond general frameworks, the general Living Lab approach and corresponding **descriptors** have been translated and specified for **Architecture Living Labs in HE environments**, creating the corresponding application framework.

ESD related competences and strategies have been associated with the 4 **main characteristic** of the Living Lab approach: the multi stakeholder approach, the user involvement approach, the open innovation approach and the real-life setting approach, stating that Living Labs can be valuable concepts for ESD and even serve as **transformational tools for HEI's transition towards SD.**

A **common conceptual framework of ESD and Living Labs** has been proposed, based on **4 common paradigms** identified as characteristic for ESD and inherent to Living Labs, namely **Pluridisciplinary Systemic Approach, Participatory Co-creative Action, Open Collaborative Process and Real-Life, Context-related Settings**.
The described communalities indicate that ESD courses and Living Lab activities are compatible and can generate **valuable synergies** between teaching, research and innovation.

The **holistic role of Architecture Living Labs for ESD in higher education** has been highlighted, specifying the three main fields of HE transformation towards SD, namely **HEI's Teaching, Research and Innovation, HEI's institutional transformation towards SD and HEI's societal outreach** and identifying how corresponding activities can serve as connecting elements between HEIs and society through fostering **internal and external transition processes** to sustainable development.

Finally, **Living Lab** activities have been related to **ESD strategies and methods** in order to exemplify the compatibility of certain methods like problem based learning and project based learning (PBL) with both approaches.

Living Labs as systemic innovation approach in HEI's

Understanding Living Labs as a **systemic innovation approach**, where multiples stakeholders participate collaboratively in the development process of a new product or service, and given that within this *value network* a user can act also as producer (Feurstein & Hesmer 2008), **an interesting translation of this generally market oriented and technology based living lab concept into the academic world of teaching, research and innovation is possible**, specifically regarding a new approach to knowledge generation and sharing, and the corresponding processes of the personal and collective definition of values and implementation of action.

Academic paradigms are shifting towards student-centered (in other words user-centered) teaching in HE. Students, but also researchers can be seen as **users of HE infrastructures and services** in order to develop their personal tasks (read: learning on one side, teaching and researching on the other). HEIs are also expected to be societal game changers **contributing to society progress** through the generation of **new knowledge**, the contribution to **societal well-being** and the implication in **societal challenges** and **value discussions**.

Academic Living Labs for teaching, research and innovation, might serve as **shared activities platforms** for all HEI's stakeholders, offering teaching and learning services to students, research and innovation environments to researchers as well as collaboration and outreach activities to society.

In the **discipline of Architecture**, and especially with the urgent need to acquire knowledge in the field of sustainability, competences regarding SD and a pluridisciplinary view on a profession in the process of profound changes, **a living lab approach could facilitate the necessary dynamic and open-ended multi-stakeholder approach in order to define *what* should be learned and *how* learning processes should be best organized** in this discipline.

Installing **academic Living Labs as dynamic platforms for co-creation and innovation** in the field of Architecture could contribute to the transformation from student-centered teaching to student-participatory teaching and learning methods, understanding students as users, but also as producers of teaching and learning processes within a **Higher Education Living Lab Ecosystem**, together with other relevant stakeholders.

6 3-STEP CLASSIFICATION TOOL FOR LIVING LABS IN ARCHITECTURE

This chapter focuses on the development of a parameter-based approach for the differentiation and evaluation of Living Lab initiatives in architecture. In a 3-step process, criteria of differentiation, methodology of descriptors and indicators, and graphic representation tools are developed and applied to the identified case studies of Living Lab initiatives of chapter 4.3.

6.1 Introduction

As shown in chapter 4, Living Labs projects and initiatives share some common generic principals, concepts and methodologies, but generally have diverse characteristics, according to the knowledge field they are focusing on, the type of infrastructure they constitute, their objectives, their stakeholders and drivers, and the socio-cultural context in which they are embedded among many other factors. Living Labs in Architecture might have more similarities among each other due to the specific field of action, the built environment, in which they operate, but they also show a huge variety of typologies.

This chapter proposes a parameter-based 3-step classification and benchmarking of Living Lab initiatives in architecture (Fig. 6.1) in order to understand better the different type of projects and their characteristics.

Criteria for differentiation and indicators of performance are established, based on the general Living Lab characteristics described in chapter 3.2 and the definition of Living Labs in Architecture according to chapter 3.3.

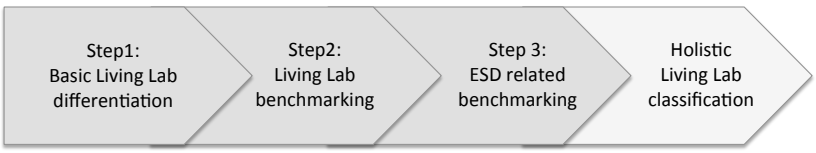


Figure 6.1 Process for a 3-step classification of Architecture Living Labs for ESD in HE

The parameters are identified which are considered significant within the existing Living Lab definition and methodology, analyzing to which extent these specific parameters might contribute to successful ESD within the related Living Lab projects.

Identifying and fostering these specific parameters contributes to a successful design, implementation and monitoring of Living Labs in Architecture with a focus on ESD in higher education. Existing initiatives can be assessed and specific actions can be taken in order to foster single parameters, improving the overall contribution to ESD of active Living Labs.

In order to develop the 3-step classification tool the following steps will be taken:

Chapter **6.2 offers a structured analysis of the classification criteria and performance indicators of living labs in architecture** according to the general definition of Living Lab methodologies and characteristics (chapter 3.2) and the described specific characteristics of Living Lab projects in architecture (chapter 3.4).

Chapter **6.3 contains a basic differentiation of Living Labs according to their principal characteristics** regarding their type of stakeholders and their approach to sustainability.

Chapter **6.4 contains a generic classification of Living Labs according to 6 principal Living Lab characteristics,** allowing an individual assessment of projects and the **ranking of projects** according to the degree of fulfillment of Living Lab criteria.

In chapter **6.5 a specific descriptive and analytical tool is proposed for a more detailed differentiation of Living Labs in Architecture according to their contribution to ESD in HEIs,** with a list of detailed characteristics and performance indicators. This tool contains a graphic representation of indicators combining three main areas of interest:

- ESD relevant parameters (ESD activity)
- Living Lab relevant characteristics (Living Lab activities)
- HEI relevant parameters (ESD context)

Parameters are identified, which are related to activities in the field of ESD, and the contribution of projects to the transformation of an HEI towards SD, giving together holistic information about the level of contribution of each project to ESD within its specific HE context.

Chapter **6.6 resumes the developed criteria and tools for differentiation** of living lab initiatives and contains **conclusions** about the methodologies developed, their applicability to different type of case studies and their utility and limitations in general.

6.2 General classification criteria of Living Labs in Architecture

This chapter introduces the classification criteria of Living Labs according to size, type, objectives, management and organizational structure, as well as their concepts for the integration of teaching, research and innovation activities according to existing living lab theory (chapter 3.2) and the derived definition of living labs in architecture (chapter 3.3). This is contrasted through the specific analysis of the 20 selected case studies of laboratories in architecture (chapter 3.5) which to a certain degree, already apply Living Lab concepts and methods or operate similar infrastructures, which have the potential to incorporate them. In the following chapters classification parameters are grouped in sets and discussed according to thematic areas.

6.2.1 Living Lab typologies according to size and setting

Living Labs can be differentiated according to the degree and type of real-life setting in which they are located (chapter 3.2). A real-life setting means its implementation within a real environment of everyday use and life, in contrast to a controlled laboratory environment.

Nevertheless, many Living Labs can be observed in "near real-life" environments, offering the possibility of simulation or real-life use of products or services, but under laboratory-like conditions of control and monitoring.

Another differentiation criterion is the physical extension or size of the Living Lab (chapter 3.2). Living Labs in Architecture can be like a laboratory, small-scale installations, prototype architecture in the tradition of historical prototype buildings (chapter 3.4), or large scale projects using existing building complexes or even city quarters in order to establish their activities.

Within Architecture Living Labs, the two differentiation criteria of setting and size are intrinsically connected to each other, as these types of Living Labs are linked to the built environment.

Having analyzed the selected 20 case studies of Living Labs in Architecture (chapter 4.3), the following main typologies can be distinguished:

- **Buildings in real-life environments** which are evaluated during regular use (e.g. Cubity, Energy Efficiency Center ZAE)
- **Living laboratory activities integrated in real-life setting**, e.g. using existing buildings or city quarters for experimentation (e.g. De Monfort Living Lab, Amsterdam City-Zen)
- **Experimental laboratory-type buildings**, with partial real-life aspects of use, in controlled environments (e.g. HfT Home+, UPM Magic Box)
- **Experimental laboratory-type installations**, allowing simulation of a real-life environment within a controlled context (e.g. MIT PlaceLab, Les Gran Ateliers)

Additional typologies might arise for a precise description of other living lab projects, for example the monitoring of a large number of dwellings under conditions of regular use or controlled elderly health care living labs in real environments of elderly residences or hospitals. Nevertheless, the above-established categories reflect a first and basic differentiation of Living Labs linked to HE environments regarding their degree of real-life setting and their size.

6.2.2 Objectives, organizational structure and stakeholders

Regarding Living Labs in Architecture, a differentiation can be made regarding the main drivers and related to this, the main objectives of a specific project.

Chapter 3.2 identifies possible types of stakeholders in living lab initiatives, focusing on their role, interest and influence on a project. A basic differentiation is made between utilizer, enabler, provider and user-driven living labs (Nyström et al. 2012).

Provider-driven Living Labs are focused on establishing an open-innovation network where all participants benefit from the knowledge and information generated. Universities for example

can use Living Labs for applied disciplinary research, but also educational research and innovation in teaching.

Alternatively, referring to the original definition of Living Labs as innovation arenas (Almirall 2009), **utilizer-driven living labs** are typically driven by *companies that launch and promote living labs to develop their businesses* (Nyström et al. 2012). Guided co-creation processes, user experiences and information about specific products or services contribute to the delivery of desired results and outcomes to companies quickly.

Considering these two main types of living labs, the university/society driven and the company/ research driven living lab projects, the following questions regarding the participating stakeholders are of interest:

- Who are the main stakeholders?
- Is there a mix of stakeholders, which allows a pluridisciplinary living lab approach?
- Is there a mix between public and private stakeholders and a participation of society (Public-Private-People Partnership)?

This gives rise to considerations about who is the main driver of a project, and what the main objectives are, as well as many related issues regarding management, life-span and expected outcomes.

6.2.3 Thematic focus and relation to teaching, research and innovation

Many research and innovation projects in different fields of knowledge use Living Labs as methodology for user-centered innovation, e.g. in the area of ICT, elderly health care, rural development, e-government or energy efficiency.

Regarding Architecture Living Labs, the following **generic focus areas** can be distinguished with different volumes of teaching, research and innovation activities, according to each individual project:

- Technical equipment of buildings (e.g. energy generation, distribution, indoor comfort)
- Construction systems and building materials (e.g. prefabrication, modular building systems, low impact building materials, smart building materials)
- Energy efficiency and energy management in buildings (e.g. Nearly Zero Energy Buildings, peak-load shifting, decentralized energy generation and storage, predicted energy performance)
- Research on Sustainable Lifestyle and related products and services (e.g. low impact lifestyles, closed material and water cycles, energy self-sufficiency)
- Research on ICT solutions in the built environment (e.g. communication, security, assisted living, smart grids, internet of things)
- Research on innovative housing concepts (e.g. co-housing, growing house concepts, flexible floor plans)

The relation of an Architecture Living Lab to the areas of teaching, research and innovation can vary widely between projects, according to their organizational structure, their main

stakeholders, their objectives, and their settings. Generally Architecture Living Labs have a strong relationship to HEIs and specifically to research departments, or alternatively to research institutions which have established links to HEIs.

This guarantees a strong **link to academic research**, namely doctorate programs of HEIs, linking PhD research to research and innovation projects with an industrial or market oriented background. Synergies are created among stakeholders, allowing benefits to HEIs from the corresponding **knowledge generation** processes, which themselves are important for **up-to-date teaching** in the related disciplines. This win-win situation, observed in other university-industry collaboration projects, can be seen as a **specific strength of HEI related Living Labs**.

6.2.4 Approach to open innovation and user-centered research

Living Labs are defined as open innovation ecosystems (Pallot et al. 2010), which bring together stakeholders in order to benefit from an accelerated cyclic innovation process, which reduces the time-to-market for new products or services (chapter 3.2).

Regarding Architecture Living Labs, and considering their specific settings and stakeholder participation as well as the typical focus areas of research, the following questions should be raised in order to differentiate their approach to innovation:

- Does the project integrate an open Innovation approach?
- Are there options for multi-stakeholder processes for innovation?
- Is there a foreseen or implemented pluridisciplinary approach to innovation?
- Does the project allow a user-centered research approach?
- Which specific role has the user in the innovation processes?

Open Innovation in this context is considered an essential part of the definition of Living Labs (Almirall 2009). Nevertheless Open Innovation is not a single methodology or process, but can be implemented with a different degree of openness, with many different classes of participating stakeholders and for very different purposes, from knowledge generation, project development up to the innovation of products and services.

Within Architecture Living Labs in HE, the transition from a participatory teaching and learning process regarding innovation towards a shared open innovation process might be fluent, and many degrees of openness can be defined.

The same considerations have to be taken into account regarding the user-centered research approach of living labs. This user-centered approach can be differentiated according to the degree of user participation in the innovation process.

As described in chapter 3.2.6, Westerlund et al. (2011) 4 steps towards open innovation through users are defined. From an initial *producer driven innovation* approach (step 1), with little or no communication or interaction with users, innovation culture can evolve towards *user-centric, closed innovation* (step 2), where user ideas get collected through surveys and user studies and also pilot testing of new products.

A next step is defined as *user-centric, open innovation* (step 3), considering users as important sources of information, involving them in part of the innovation process through co-creation, critical feedback and suggestions for further improvements without involving the user over the full innovation process lifecycle.

Finally a *user-driven innovation* approach (step 4) has been identified, where customers lead the development work in an open way. (Westerlund et al. 2011)

These 4 different degrees of user involvement in the innovation process can be used to differentiate between types of living lab initiatives according to their way of integrating the user in collaborative processes of knowledge generation and innovation.

6.2.5 Synergies between Living Labs and ESD in HEIs

A major importance of this study is its contribution to research on the relation between a new methodology regarding user-centered innovation in real-life environments through Living Labs in Architecture, and an analysis of the potential of this new methodology for supporting and fostering ESD at HEIs with a specific focus on Schools of Architecture.

Under the overall objective of fostering ESD at HEIs, it is of major interest to investigate possible synergies between a newly introduced innovation methodology, strongly related to a different kind of experimental infrastructures as used today in HE, and a different ESD relevant teaching and learning model which can be linked to it.

Different descriptive and content related parameters must be analyzed in parallel in order to see whether within a general framework of HE teaching and learning activities, additional expectations of ESD related learning outcomes and competences can be met within this type of new, experimental learning environment of a Living Lab and its innovation focused, user-centered research activities.

The following steps are considered relevant in order to approach this research question:

- Definition of ESD relevant learning outcomes, competences, skills and knowledge in the field of Architecture
- Evaluation of teaching and learning strategies, tools and techniques applied in Architecture Living Labs and their relevance to ESD
- Assessment of ESD learning outcomes of Architecture Living Labs in HE, and their comparison with other teaching and learning activities and formats

This research is case study based, as there is no established theoretical framework about Living Labs and what they can contribute to HEI environments, a lack of definition of ESD in discipline-based studies like Architecture and a considerable diversity of individual Living Lab projects and initiatives. Specific field studies and individual case studies allow bringing together concepts, strategies, and experiences in order to summarize achieved outcomes and successful initiatives as well as drawbacks and weak points, opening up this specific field for further research.

Based on the previously discussed differentiation parameters, the ESD theory of chapter 2 and the definition of Living Labs in chapter 3, as well as the specific analyzed case studies of

Architecture Living Labs (chapter 4), the following chapters introduce and describe these type of projects in 3 levels of differentiation.

6.3 Step 1: Basic differentiation of Architecture Living Labs

As the first step of classification of Architecture Living Labs, a basic differentiation is proposed according to the principal characteristics regarding their physical setting, their main stakeholders and declared objectives as well as their apparent role in relation to teaching, research and innovation. This first differentiation allows visualizing Living Lab projects on a two-axis graph, which shows their principal characteristics and allows mapping and comparison between a large number of projects in order to detect similarities and differences.

6.3.1 Methodology

Parameters for a first basic differentiation are identified through review, analysis and comparison of the identified 20 living lab case studies, described in chapter 4.3. Public available information is used in order to identify basic parameters and characteristics of each project. Differentiation parameters are limited to 2 main characteristics in order to offer a simplified differentiation of Architecture Living Labs. A two-axis graph is set up in order to visualize the basic differentiation between different living lab projects.

6.3.2 Criteria of basic differentiation

The following 2 main criteria are selected for this first stage of differentiation.

Industry/Research versus University/Society based stakeholders and setting

The initial criterion for the differentiation of Living Labs is the type of principal stakeholders of a project. Primary stakeholders are the main drivers responsible for a living lab project. Architecture Living Labs can be set up and driven by private or public stakeholders. Private stakeholders are generally companies or private research institutes; public stakeholders are mainly universities or public administration, e.g. a city administration.

This differentiation is considered important, as industry/research oriented stakeholders are generally more **market oriented**, discipline focused and interested in a specific **product or service development** over a limited time-span.

Public stakeholders on the other hand are often interested in a broad **outreach to society,** and an **open knowledge generation** and dissemination process. Return of investment through market viable products or services are generally not the main objective, which is societal well-being, innovation and knowledge dissemination.

The analysis of case studies shows that in the majority of projects private and public stakeholders collaborate based on a Private-Public-Partnership (PPP). Nevertheless, the weight and influence of each type of partner is different in each project.

Related to the profile of the primary stakeholder and of similar importance, is the setting of a Living Lab project. Private-driven projects might often be located within a controlled

environment within a company, with fewer possibilities for the generation of synergies, and subordinated to the primary interest of that company or a research institute.
Public-driven projects are mainly located in the public domain, like university campuses or public space in cities. This opens up more possibilities for involvement of citizens and other societal stakeholders, in order to co-create new ideas and solutions often related to social innovation.

Disciplinary versus holistic approach to sustainability
A second important criterion for the differentiation of Living Labs in Architecture can be the more disciplinary or holistic approach to sustainability.
Private-driven projects might generally have a more disciplinary focus for example, on specific technologies like renewable energy or technologies related to energy efficiency in order to develop, test and innovate on a certain technological product or service.
Public-driven projects might integrate a more holistic approach to sustainability to a greater degree, focused on the social impact of innovations, the user-technology interaction or a mixture between user participation and knowledge dissemination in society.

Basic differentiation of Living Labs in Architecture in 4 categories
According to the primarily identified purpose and orientation of each initiative, a basic differentiation into the following 4 groups is proposed and discussed trough specific case studies as examples of each established category.

A. University/Society based technology oriented Living Labs
These type of Living Labs have a more technology oriented research focus e.g. for low energy architecture and renewable energy. Many projects consist of prototypes, developed and built through strong university/industry collaboration and driven by the HEIs as the main stakeholder. Prototype monitoring and performance evaluation under real conditions of use are main activities related to these kinds of projects, generating relevant knowledge about innovative technological solutions and concepts. Living Labs of this type are generally located at a university campus or similar location closely related to HEIs.

Example of a University/Society based technology oriented Living Lab: **home+ *(SDE 2010)* (Case Study 12**

B. Industry/Research based technology oriented Living Labs
These types of Living Labs have a strong industry or research based focus, with private companies or research institutes as important or main stakeholders. They are focused on the development and testing of technological innovation of products and systems, in association with industry. Established research capacities including prototype development and evaluation within real-life environments are characteristic. University collaboration is typical, even if the main stakeholder is a research institute with a strong industrial influence.
User-centered research is applied basically through the evaluation of technology in laboratory settings, which simulate real-life environments, or through the user evaluation in prototype buildings. User-driven innovation is generally not applied.

Example of an Industry/Research based technology oriented Living Lab:
Energy Efficiency Center (Case Study R01)

C. Industry/Research based holistic Living Labs

These types of Living Labs have a strong industrial or research based focus, with private companies or research institutes as important or main stakeholder. They are focused on the development of holistic solutions for sustainability related challenges, which might consist of innovative products or services generally developed together with industry.
The principle characteristics are strong research capacities including prototype development and evaluation within real-life environments, and a holistic approach to sustainability through pluridisciplinary collaborations. .Holistic House-User-Interaction research with sophisticated data collection and monitoring is applied to provide user-centered performance evaluation.

Example of an Industry/Research based holistic Living Lab: **Fraunhofer InHaus Center (Case Study R02)**

D. University/Society based holistic Living Labs

These types of Living Labs have a strongly society based focus, with universities as the important or main stakeholder. They are focused on the development of holistic solutions for the sustainability related challenges of society, which might consist of innovative products or services, e.g. holistic House-User-Resource concepts or innovations for a more sustainable life-style, or on a larger scale all types of social innovations.
Due to their location within or near to HEIs teaching, research and innovation activities can take place, generating synergies among the different fields of academic activity.
Projects are often based on private-public stakeholder collaborations with industry, interested in obtaining results for their product, and service innovation and development.

Example of a University/Society based holistic Living Lab:
PASaPAS *(SDE 2012)* (Case Study R16)

This differentiation into **4 main categories of living labs**, according to the type of main stakeholders and their approach to sustainability, provides a first-step for the classification of Living Labs in Architecture as shown in Figure 6.2.

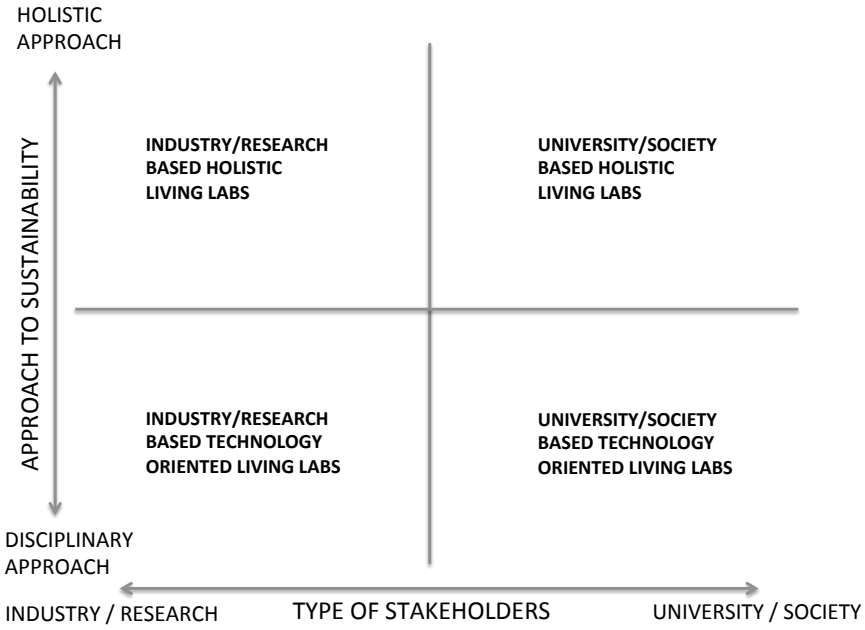


Figure 6.2 Basic differentiation of Architecture Living Labs according to the type of stakeholders and approach to sustainability

This basic differentiation and resulting *mapping* of projects allows the identification of the main characteristics of a Living Lab initiative at first glance, and facilitates first comparisons of different projects.

6.3.3 Application to 20 identified case studies

The proposed first step differentiation methodology of Architecture Living Labs is applied in the following 20 case studies described in chapter 4.3. Data has been gathered through public available information (website, publications) about the individual initiatives and projects and in some cases personal interviews with the people responsible. This leads to a generic classification in three main groups for each axis:

Horizontal axis: Industry/Research-based stakeholders, mixed stakeholders, University/Society-based stakeholders.

Vertical axis: Disciplinary approach to sustainability, mixed approach to sustainability, holistic approach to sustainability.

The location of each project in figure 6.3 is based on the available information about each project's main characteristics into one of the nine possible sectors of the graph. This position is not based on numeric parameters or indicators which would define their position in terms of exact coordinates.

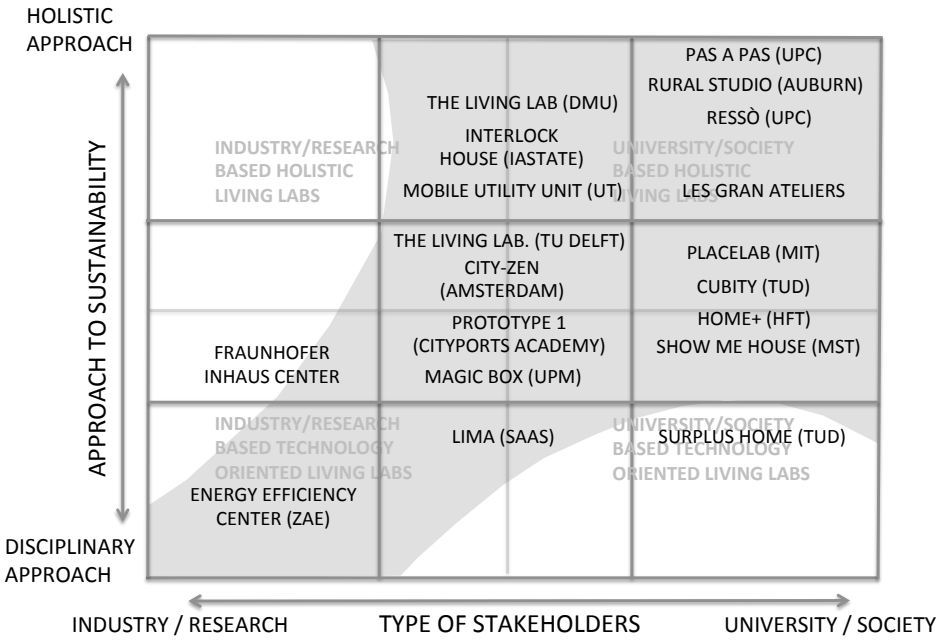


Figure 6.3 Step 1: Basic Differentiation of Architecture Living Labs regarding their approach to sustainability and their type of main stakeholders

Once attributed to a specific sector of the graph, each project's final location results from the comparison with the other case studies in the same sector, giving it a vertical position relative to them. This also means that a different selection of projects might change the relative position of projects in the same sector.

6.3.4 Discussion of established differentiation

This first differentiation of Living Labs in Architecture allows for siting projects on a common double axis graph and allows the differentiation of projects with a very disciplinary approach from others with a holistic and pluridisciplinary approach to sustainability.

Projects driven by private stakeholders like companies or research institutes are generally more market-oriented and can be differentiated from others which are driven by universities or other public stakeholders, and are generally more society oriented and less market driven.

The 20 analyzed case studies are distributed on a diagonal axis from disciplinary, industry/research based to holistic, university/society based Living Lab projects, with only one project being clearly disciplinary and industry/research based (Energy Efficiency Center (ZAE)). One project can be considered industry/research based with a mixed (disciplinary and holistic) approach to sustainability (Fraunhofer InHaus Center), but no project is shown to be industry/research based and at the same time focused holistically on sustainability.

Four projects can be found in a middle position, drawing from a mixed stakeholder approach and a mixed sustainability focus. Within this mixed stakeholder approach, one project can be

considered disciplinary focused (LIMA) and three holistically focused on sustainability. University/society based living labs show to be focused on holistic (4 projects) or mixed approaches (4 projects) to sustainability, with only one project (SurPLUShome (TUD)) being considered disciplinary focused regarding its sustainability approach.

Summing-up, there seems to be a certain prevalence for disciplinary focused Living Labs which are industry/research driven, whereas more holistic Living Lab initiatives often seem to be university/society driven or have a mixed stakeholder group as main driver.

6.4 Step 2: Generic classification of Architecture Living Labs

The second step of classification of Living Labs in Architecture consists of the evaluation of principal Living Lab characteristics, as identified in chapter 3.2, and additional parameters related to outcomes and structure in order to create a detailed picture of individual projects.

The proposed generic classification of Living Lab initiatives allows:

- Analyzing the degree of implementation of different Living Lab characteristics in a specific project.
- Comparing different Living Lab projects regarding their individual characteristics.
- Establishing an overall ranking of Living Lab projects according to the degree of implementation of Living Lab characteristics.

6.4.1 Methodology

Six basic benchmarking parameters are defined in order to assess the degree of fulfillment of Living Lab characteristics of a project.
Four parameters out of six are derived from the generic definition of Living Labs (chapter 3.2), namely **multi stakeholder approach, user involvement, Open Innovation and real-life environment**. Two additional parameters have been introduced regarding outcomes and the structure of projects, considering demonstrated **outcomes** and a consolidated **organization and structure** to be important indicators of successful Living Lab projects. All benchmarking parameters are assessed through the study of publicly available information about each project (websites, publications), and personal information from project leaders in some cases (semi-structured interviews, online inquiries).

Each performance indicator can be fully covered, widely covered, partially covered, or not covered in a certain project, resulting in a score of 3, 2, 1 or 0. (Fig. 6.4)

Indicators	Fully covered	Widely covered	Partially covered	Not covered
				
Score	3	2	1	0

Figure 6.4 Scoring system for benchmarking parameters of Living Labs

Based on the evaluation of all six benchmarking parameters, an **overall rating (0-18)** is indicated for each project as **sum of the individual scores**.

The overall ratings obtained for all 20 case studies are listed and the resulting ranking is discussed. The overall rating allows conclusions to be drawn about the degree of accomplishment of a Living Lab concept. The overall ranking allows the comparison of Living Lab initiatives between each other, identifying more and less successful examples and tracking their evolution over time through the regular update of information.

6.4.2 Benchmarking Parameters for Living Labs in Architecture

The following parameters are identified as relevant for the benchmarking of Living Labs in assessing the application of the corresponding Living Lab principles and methods.

Multi stakeholder approach: in order to foster the holistic and integrating approach of the Living Labs in research and innovation, companies, academics, administration and society have to be organized in order to collaborate as a community. The assessment of the variety of stakeholders is therefore an important characteristic, as is the diversity of disciplines, which are involved in a project. (see chapter 3.2.2)

User involvement: Living Labs are places to foster **user-centered research, capturing user insights and even allow active user participation** in innovation through co-creation processes. Living Labs allow the structure and management of user involvement in order to integrate them into the innovation process. (see chapter 3.2.3)

Open Innovation: Open innovation constitutes an **alternative concept to closed "in house" innovation** approaches. Open innovation is a form of distributed innovation and refers to collaboration with external agents in order to accelerate processes of innovation. (see chapter 3.2.4)

Real-life settings: Living Labs are generally settled in real-life environments, as outcome of user-centered research will usually be much more significant. Complexity of real environments and context contribute to realistic outcomes within a **human centric approach** to innovations. (see chapter 3.2.5)

Outcomes: Outcomes are important as indicators for the **operation and successful concept** of a Living Lab. Outcomes can be achieved in different forms like generated knowledge, ideas, networking, matchmaking, products, services or patents.

Organization and structure: Organization and structure should allow **continuity** of a project regarding its human and economic resources, but also allow **adaptability** to future requirements.

Table 6.1 shows the 6 benchmarking parameters, including a short explanation of their interpretation. These descriptions have been used in the online inquiry sent to project leaders in order to receive their self-evaluation.

1. BASED ON A MULTI STAKEHOLDER APPROACH	Based on active collaboration of variety of public and private stakeholders as innovation actors.
2. INVOLVES USERS IN INNOVATION PROCESSES	Applies user-centered research like user observation, user participation or user co-creation.
3. FOSTERS OPEN INNOVATION PROCESSES	Brings together actors and manages participatory, Open Innovation (OI) activities.
4. OPERATES IN REAL-LIFE ENVIRONMENT	Carries out Living Lab activities like monitoring of user behavior or co-creation in real-life settings.
5. GENERATES VALUABLE OUTCOMES	Generates knowledge, ideas, networking, matchmaking, products, services or patents.
6. CONSOLIDATED ORGANIZATION AND STRUCTURE	Consolidated management structure and resources allow continuity over time.

Table 6.1 Parameters for benchmarking of Living Lab characteristics

6.4.3 Graphic representation of Living Lab benchmarking data

In order to visualize the degree of fulfillment of the defined Living Lab benchmarking parameters, a **graphic representation tool** is used (Fig. 6.5), giving information about the individual performance of each of the 6 parameters as well as the overall performance in the form of the sum of the individual achieved scores.

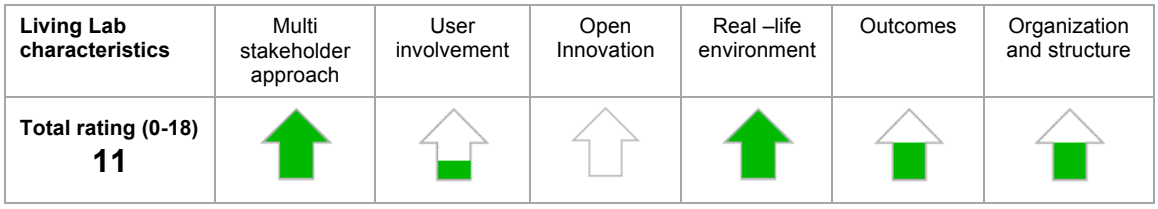


Figure 6.5 Graphic representation tool for generic classification of Living Lab projects

Integrated into the project data sheets of each case study (see Appendix II), immediate information is available about the specific strengths as well as weaknesses of individual Living Lab projects, allowing a first comparison between different approaches.

6.4.4 Application to 20 identified case studies

In the following table 6.2, all 20 case studies of recent Architecture Living Labs are listed with their corresponding overall ratings Fig 6.2). The detailed scores for each Living Lab parameter can be found in the corresponding project data sheets (see Appendix 2).

Generic classification according to Living Lab benchmarking parameters	Rating (0-18)
R01_ Energy Efficiency Center	14
R02_ Fraunhofer InHaus Center	16
R03_ City-zen Test Living Lab	8
R04_ Living Lab.	11
R05_ Cubity	14
R06_ Rural Studio- House for poor people	16
R07_ Les Grands Ateliers	16
R08_ The Living Lab IESD	11
R09_ The Show Me house - *Solar Village*	13
R10_ surPLUShome - *Solare Lichtwiese*	11
R11_ Magic Box - *Campus Montegancedo*	10
R12_ home +	10
R13_ Mobile Utility Unit - *CMPBS*	10
R14_ Interlock house	12
R15_ Living Lab LOW3	11
R16_ PASaPAS	14
R17_ Ressò	12
R18_ LIMA	9
R19_ Prototype 1 - *Concept House Village*	15
R20_ PlaceLab - *House_n*	15

Table 6.2 Classification of Living Labs according to fulfillment of living lab characteristics

6.4.5 Discussion of established differentiation and ranking

It can be stated that the ratings of the 20 selected case studies of recent Living Lab projects **range from 8 to 16**. This means that almost all projects (with exception of City-zen (R03), rated 8) have received at least half of the overall possible score, and therefore might be considered Living Labs.

Low ranked projects like LIMA (R18) or Mobile Utility Unit (R13), home+ (R12), Magic Box (R11) often lack user involvement, do not apply open innovation strategies or fail regarding the diversity of stakeholders.

Some projects like City-zen (R03), Living Lab. (R04), The Living Lab IESD (R08) and Ressò (R17) are **missing tangible outcomes for not having been** implemented yet. These projects will receive higher ratings when activities are implemented in the near future.

The specific **group of Solar Decathlon Solar houses** (R09-R17) shows ratings between 10 and 14. Some projects do have a clear focus on technology research (home+ (R12), Magic Box (R11)) and do not focus much on the user, while others like The Show Me house (R09), Mobile Utility Unit (R13) or surPLUShome (R10) are used as infrastructures (office, housing, meeting space), with only limited use as research and innovation infrastructure.

Industry/Research based Living Labs like Energy Efficiency Center (R01) and Fraunhofer InHaus Center (R02) are rated high, as both draw from a multi stakeholder approach within a consolidated organization and management structure and have demonstrated outcomes. As minor weak points of these two projects may be considered some limitations in the user involvement (Energy Efficiency Center (R01)) and in the operation in real-life environments (Fraunhofer InHaus Center (R02)), but both represent an overall complete concept of a Living Lab.

A **strong user involvement** in a real-life setting with a sound diversity of stakeholders can be stated for PASaPAS (R16) and Ressò (R17) as community or neighborhood laboratories, and also Prototype 1 (R19) and PlaceLab-House (R20) as observational infrastructures for innovative housing concepts.

Some other concepts of Living Labs like Cubity (R05), Les Grands Ateliers (R07) or the Interlock House (R14) also show a good rating with regard to their Living Lab approach, all of them with considerably **unique characters**.

Finally Rural Studio – House for poor people (R06) must be mentioned as a unique, **decentralized Living Lab project with** many small Living Labs in form of family houses built in a participatory process for the local community. This project can be considered opposite to the industry and research related Fraunhofer InHaus Center (R02), although both received the same highest rating within this ranking of projects.

This benchmarking of projects regarding their conceptual Living Lab approach shows that Architecture Living Labs can be established in **many different contexts** and in many different forms, and still share their basic **common principles**. There is no unique form or concept for a Living Lab. **Diversity** forms part of the approach.

6.5 Step 3: Holistic representation of Architecture Living Labs for ESD in HE

Living Labs in HEI environments are strongly related to academic teaching and research activities. Each project therefore has a specific potential for **contributing to ESD in HEIs** according to its specific characteristics as Living Lab, its operational structure and its approach to sustainability. This is an important aspect to assess as **this research work establishes the hypothesis that Living Labs in Architecture would be efficient tools for ESD in HE**.
In consequence, this **third classification step** of Architecture Living Labs consists in a **holistic benchmarking** regarding their **ESD related activities** as well as their contribution to the **HEI's transformational processes** towards SD. Together with a further detailed benchmarking of their Living Lab characteristics (step 2), this allows a holistic assessment and description of these specific types of projects.

The resulting detailed descriptive tool of Living Lab initiatives allows:

- Representing holistically SD related qualities of a Living Lab project in HE in relation to its specific Living Lab approach.
- Comparing the degree of implementation of different ESD / SD / Living Lab characteristics in different projects.
- Identifying specific parameters of Architecture Living Labs, which could be beneficial for their capacity of fostering ESD in HE environments
- Establishing an overall ranking of projects according to their degree of successful implementation as Living Labs for ESD in HEIs.

6.5.1 Methodology

Benchmarking parameters are divided into three main areas:

- ESD relevant characteristics (ESD activities)
- Living Lab relevant characteristics (Living Lab activities)
- HEI relevant characteristics (HEI context)

For each of the **3 main areas of benchmarking** of an ESD related Living Lab in Architecture, **six basic benchmarking parameters** are defined and **3 sub-indicators** are identified for each parameter, allowing description and assessment of the performance of each parameter in more detail. **Parameters and sub-indicators derive from the described framework of Living Labs in Architecture (chapter 3.3), the framework for ESD in the field of Architecture (chapter 2.3) and the discussion about the transition processes of HEI's towards SD (chapter 5.5).**

At this stage many of the benchmarking values will be based on approximations according to the depth of the available information. Nevertheless the mixture of sources of information, including personal interviews with project leaders, online questionnaires and free available published information, might allow a reasonable approximation to each project's characteristics in order to compare them amongst each other.

6.5.2 Benchmarking Parameters for Living Labs in Architecture for ESD in HEIs

Tables 6.3, 6.4 and 6.5 show the specific proposal for 6 main parameter and their corresponding 3 sub-indicators for each of the 3 defined benchmarking areas.

Benchmarking area 1: ESD approach			
Main parameter	Sub-indicator 1	Sub-indicator 2	Sub-indicator 3
1. ATTENDS THEMATIC FIELDS OF ESD	Attends different thematic fields related to ESD *e.g. materials/energy and environment, sustainable production/consumption*	Combines disciplinary SD knowledge and ESD knowledge *e.g. holistic approach to the energy systems and technologies*	Approaches ESD relevant thematic fields at different levels *e.g. attends micro, meso and macro level, individual vs. societal point of view*
2. FOSTERS SPECIFIC ESD COMPETENCES	Learning outcomes are focused on ESD specific competences *e.g. system thinking, anticipatory competence, normative competence, strategic competence*	Fosters a mixture of ESD specific and generic competences *e.g. critical thinking, team working, dealing with uncertainty, leadership interdisciplinarity*	Trains competences through advanced strategies and methods *e.g. debate, project based learning, experience based learning, societal projects, value discussions*
3. APPLIES ESD FAVORABLE METHODS AND TOOLS	Offers a mixture of cognitive and active learning experiences *e.g. combining knowledge generation and reflection, with group experiences*	Applies project based learning (PBL) or similar methods *e.g. designing and implementing of a community project*	Fosters participation processes at different levels *e.g. co-creation activities, common vision building, group work*
4. USES ESD FAVORABLE TEACHING STRATEGIES	Creates collaborative Learning Environments for group work *e.g. physical and virtual places to meet and exchange*	Uses participatory course design and evaluation methods *e.g. collective definition of learning outcomes, peer to peer evaluation*	Offers a non-formal, experience-based learning environment *e.g. spaces which inspire debate, group work, dialog, value discussions*
5. CREATES SD SPECIFIC USEFUL OUTCOMES	Creates outcomes for specific SD related societal problems or projects *e.g. community problems and conflicts like energy poverty*	Creates knowledge for action according to sustainability science definition *e.g. generates applicable solutions for problems or challenges of society*	Creates diverse outreach to society in the field of teaching and learning for SD *e.g. continuous learning initiatives, open-doors days, publications*
6. FOSTERS THE CREATION OF NEW VALUES FOR TRANSFORMATION TOWARDS SD	Creates an environment for open value discussions *e.g. places for debate and personal interchange*	Fosters value sharing, reflection and collective transformation *e.g. debate, personal statement and positioning*	Attends aspects of personal development of people *e.g. development of an eco-consciousness*

Table 6.3 Parameters for benchmarking of the ESD approach (including sub-indicators)

Benchmarking area 2: Living Lab approach			
Main parameter	**Sub-indicator 1**	**Sub-indicator 2**	**Sub-indicator 3**
1. BASED ON A MULTI STAKEHOLDER APPROACH	Has a variety of stakeholders of the public and private sector (PPP) *Stakeholder mix*	Fulfills the role of a broker/intermediary between a series of innovation actors *Number of stakeholders*	Creates an active and efficient collaboration network between stakeholders *Strategic approach*
2. INVOLVES USERS IN INNOVATION PROCESSES	Applies user-centered research with users as passive subjects (Observation) *Experience yes/no*	Applies user-centered research with users as active subjects (Participation) *Experience yes/no*	Integrates users as co-creator in innovation activities (User as driver) *Experience yes/no*
3. FOSTERS OPEN INNOVATION PROCESSES	Brings together actors for participatory, Open Innovation (OI) activities *Experience yes/no* *Number of activities*	Manages efficiently Open Innovation processes (legal and organizational issues) *Management and protocols for OI*	Generates valuable outcomes through open innovation processes *Number of products / services / patents*
4. OPERATES IN REAL-LIFE ENVIRONMENT	Carries out Living Lab activities in real-life settings *Degree of real-life settings*	Monitors user behavior in real-life environments *Degree of user monitoring*	Real-life settings are embedded in real-life contexts *Degree of real-life context*
5. GENERATES VALUABLE OUTCOMES	Generates new knowledge and ideas *Volume of generated knowledge and ideas*	Generates networking and matchmaking *Number of events, number of projects*	Generates patents, products or services *Number of patents, products and services*
6. CONSOLIDATED ORGANIZATION AND STRUCTURE	Project is based on a consolidated management structure *Organizational solidity*	Structure guarantees resources for continuity in time *Financial and human resources*	Organization allows adaptation to changes over time *Conceptual and technological adaptability*

Table 6.4 Parameters for benchmarking of the Living Lab approach (including sub-indicators)

Benchmarking area 3: HEIs SD transition			
Main parameter	**Sub-indicator 1**	**Sub-indicator 2**	**Sub-indicator 3**
1. FOSTERS INNOVATION IN TEACHING AND LEARNING FOR SD	Applies innovative teaching and learning strategies regarding ESD *e.g. project based learning on SD issues, experience based learning virtual learning platforms*	Collaborates within HEIs in ESD related educational innovation projects *e.g. participation in ESD programs, HEI internal ESD research initiatives and networks*	Participates in international projects or networks regarding ESD *e.g. international collaborations with other HEIs, financed research on ESD innovation*
2. SUPPORTS HEI'S TRANSITION PROCESSES TOWARDS SD	Fosters institutional transition through specific activities and projects *e.g. supporting SD /ESD projects, organize SD/ESD workshops, collaborates in working groups*	Outcomes get applied to HEI's infrastructure, operation or management *e.g. energy efficiency improvements or resource efficient management strategies*	Serves as platform for testing SD approaches to teaching, research and innovation *e.g. sustainability science approach, open innovation processes, social learning networks*
3. FOSTERS HIGHER EDUCATION INSTITUTIONS' OUTREACH TO SOCIETY	Includes societal stakeholders (citizens, public administration, local companies) *e.g. private public partnerships (PPP) or similar collaborations*	Contributes to dissemination of SD relevant knowledge to society *e.g. open doors days, publications, educational activities*	Works on societal relevant questions and projects together with local stakeholders *e.g. community challenges, collaboration projects, consulting*
4. FUNCTIONS AS A PLATFORM FOR TRANS DISCIPLINARY COLLABORATION	Brings together different disciplinary fields for collaboration *e.g. architects, engineers, sociologist, designers*	Offers a place for transdisciplinary debate and knowledge sharing *e.g. conferences, debates, virtual platform*	Applies strategies for fostering synergies between disciplines *e.g. matchmaking for projects, co-creation workshops, networking*
5. SUPPORTS BOTTOM UP PROJECTS AND NEW INITIATIVES REGARDING ESD / SD	Offers space for new ESD / SD related projects and initiatives *e.g. student projects, employee initiatives*	Fosters actively new bottom-up projects regarding ESD / SD *e.g. through consultancy, promotion, networking*	Manages new bottom-up projects for market implementation *e.g. through prototyping, financing, business plan*
6. OFFERS A SHARED SPACE FOR MANY USER GROUPS IN AND OUTSIDE HIGHER EDUCATION (HE)	Offers a place for ESD at all levels, from high school to PhD level and for citizens in general *e.g. through guided visits, experiments, expositions and research space*	Brings together teaching, research and innovation activities in one place *e.g. a prototype house, used for teaching, research and innovation*	Creates efficiently synergies between different user groups, projects and entities *e.g. integrates students in research projects or innovation workshops*

Table 6.5 Parameters for benchmarking of the approach to HEIs' SD transition (including sub-indicators)

6.5.3 Data gathering and limitations

As the first step, information about the characteristics of each project like its objectives, organization, funding, infrastructure, stakeholders, outcomes, results and other available parameters are collected from public available information like websites, publications, articles, reports, and similar documents.
In a second step, additional information has been gathered through an online questionnaire designed and sent to Living Lab project leaders via email.
For some projects it has been additionally possible to carry out personal interviews with the people responsible in order to gather additional detailed information and personal reflections about the initiatives, using Skype conversations, telephone calls or personal meetings.

Limitations of data acquisition:

Due to the number of **54 sub-indicators** related above, it has not been possible to raise the corresponding detailed data through online questionnaires directly from the project leaders. Instead a **simplified inquiry** has been used, asking for one single rating of each benchmarking parameter, extending the approach of step 2 (chapter 6.4) to the fields of ESD and HEIs.

The following parameters have been assessed:

Benchmarking area 1: ESD approach	
1. ATTENDS THEMATIC FIELDS OF ESD	Attends different thematic fields related to ESD, combining disciplinary SD knowledge and ESD knowledge at different levels.
2. FOSTERS SPECIFIC ESD COMPETENCES	Trains generic and ESD specific competences through advanced strategies and methods.
3. APPLIES ESD FAVOURABLE METHODS AND TOOLS	Offers a mixture of cognitive and active learning experiences, e.g. co-creation processes within project based learning.
4. USES ESD FAVOURABLE TEACHING STRATEGIES	Creates collaborative Learning Environments, non-formal, experience-based learning or participatory course design.
5. CREATES SD SPECIFIC USEFUL OUTCOMES	Creates outcomes for specific SD related societal problems or projects, knowledge for action or ESD outreach activities to society.
6. FOSTERS THE CREATION OF NEW VALUES FOR SD TRANSITION	Creates an environment for open value discussions, fostering value sharing, reflection, transition and the personal development of people.

Table 6.6 Parameters for benchmarking of the ESD approach (simplified)

Benchmarking area 2: Living Lab approach	
1. BASED ON A MULTI STAKEHOLDER APPROACH	Based on active collaboration of variety of public and private stakeholders as innovation actors.
2. INVOLVES USERS IN INNOVATION PROCESSES	Applies user-centered research like user observation, user participation or user co-creation.
3. FOSTERS OPEN INNOVATION PROCESSES	Brings together actors and manages participatory, Open Innovation (OI) activities.
4. OPERATES IN REAL-LIFE ENVIRONMENT	Carries out Living Lab activities like monitoring of user behavior or co-creation in real-life settings.
5. GENERATES VALUABLE OUTCOMES	Generates knowledge, ideas, networking, matchmaking, products, services or patents.
6. CONSOLIDATED ORGANIZATION AND STRUCTURE	Consolidated management structure and resources allow continuity over time.

Table 6.7 Parameters for benchmarking of the Living Lab approach (simplified)

Benchmarking area 3: HEIs' SD transition	
1. FOSTERS INNOVATION IN TEACHING AND LEARNING FOR SD	Applies innovative teaching and learning strategies regarding ESD and participates in ESD related educational innovation projects or networks.
2. SUPPORTS HEI'S TRANSFORMATION PROCESSES TOWARDS SD	Fosters institutional transformation through specific activities and projects, serving as platform for new SD approaches within HEIs, applying outcomes within the own context.
3. FOSTERS HIGHER EDUCATION INSTITUTIONS' OUTREACH TO SOCIETY	Includes societal stakeholders (citizens, public administration, local companies, etc.), disseminates SDE knowledge and collaborates with local stakeholders on specific projects.
4. FUNCTIONS AS A PLATFORM FOR TRANSDISCIPLINARY COLLABORATION	Brings together different disciplinary fields for collaboration, fostering transdisciplinary debate and knowledge sharing, and the creation of synergies.
5. SUPPORTS BOTTOM UP PROJECTS AND NEW INITIATIVES REGARDING ESD / SD	Offers space for new ESD / SD related projects and initiatives, fostering and managing actively new bottom-up projects.
6. OFFERS A SHARED SPACE FOR MANY USER GROUPS IN AND OUTSIDE HIGHER EDUCATION (HE)	Offers a place for ESD at all levels, from high school to PhD level and for citizens in general, bringing together teaching, research and innovation activities, creating synergies among groups.

Table 6.8 Parameters for benchmarking of the approach to HEIs' SD transition (simplified)

Other limitations:
The selected benchmarking parameters should be discussed regarding their importance to each specific type of project. A differentiated weighting for individual parameters and sub-indicators might be helpful, as well as their selection and total number might be the object of further reflections. This process is not possible within the limits of this work but will be part of future related research.

6.5.4 Holistic graphic representation of Living Lab benchmarking data

A graphic representation tool has been developed in order to visualize the performance of Architecture Living Labs in the three areas defined above. On a 0-9 scale each benchmarking parameter indicates its performance numerically and contributes to the overall **visualization of strengths and weaknesses** of a project in certain areas.

The developed graphic representation tool can also be applied to more than one project at once, showing the relative performance of a project regarding the other for each parameter.

The following representations serve as example in order to demonstrate the tool (Fig.6.6):

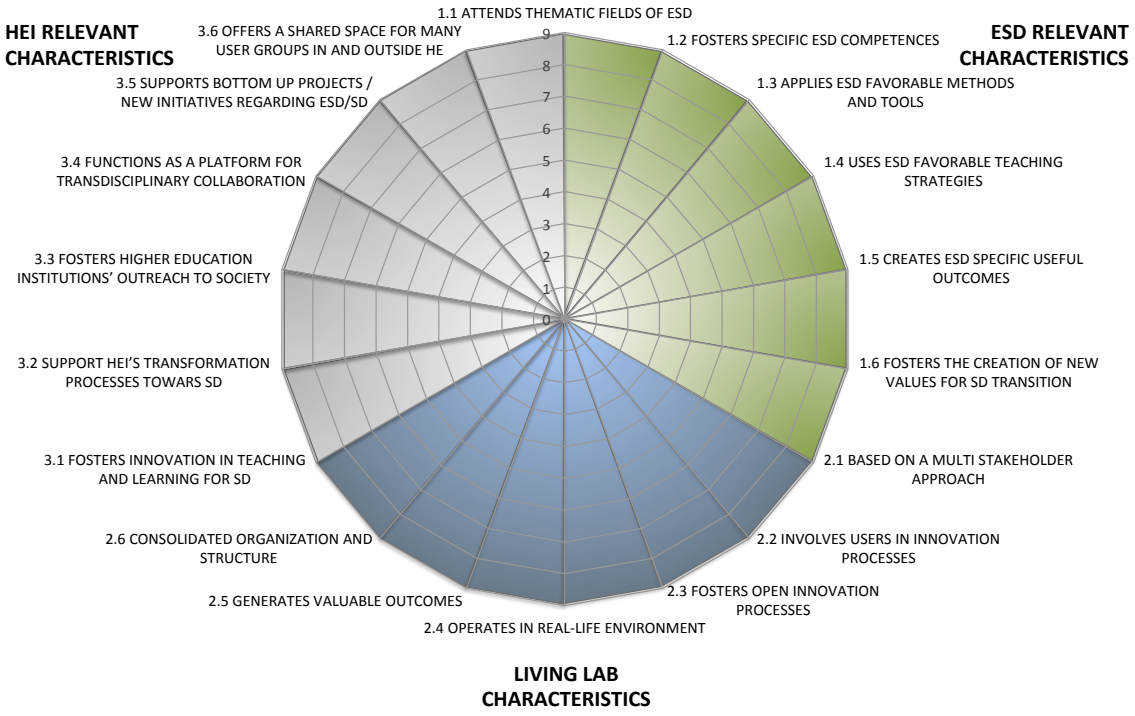


Figure 6.6 Example for the holistic graphic representation of Architecture Living Labs for ESD in HEIs.

6.5.5 Application to 5 identified case studies

In the following section, several recent Living Lab case studies are assessed through an online questionnaire to their project leaders, which reflects the understanding of the project by those responsible.

Fraunhofer-inHaus-Center (Fraunhofer) (case study R02)

Fraunhofer inHaus-Center belongs to the Fraunhofer Gesellschaft, Europe's largest applied research organization and has a powerful concept to offer **integrated chain of innovation from research through to application and market**, based on application labs.

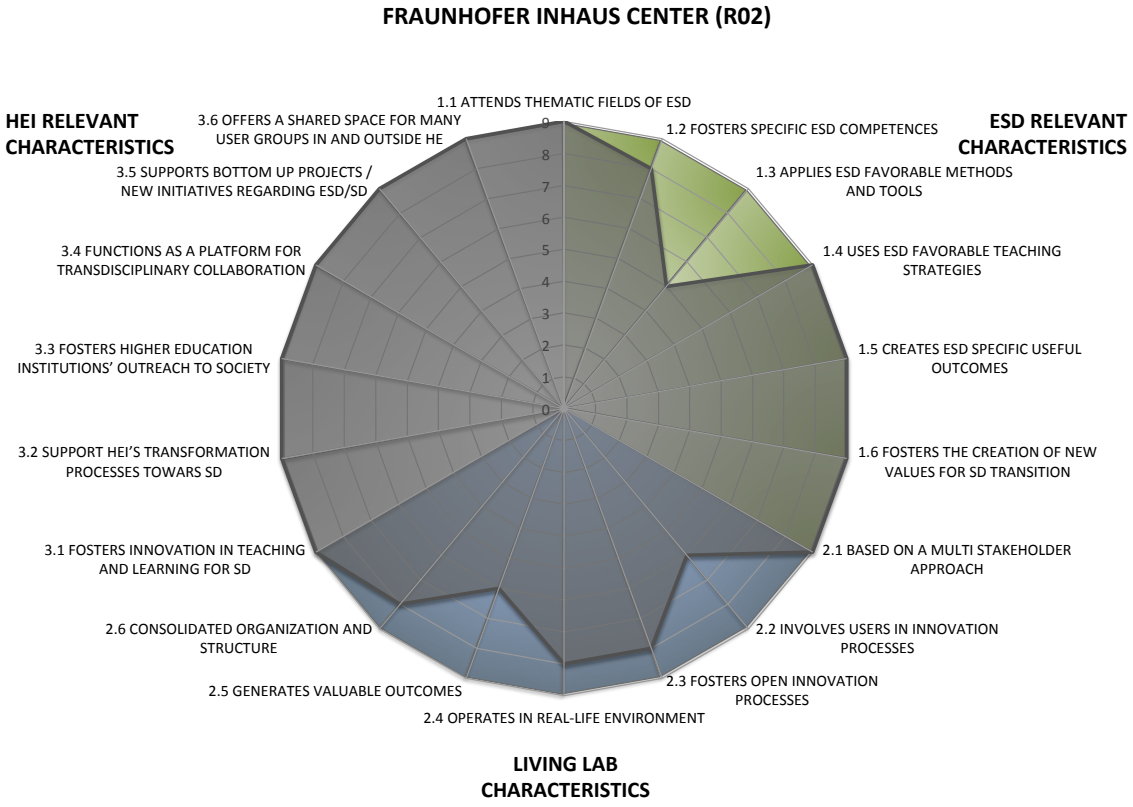


Figure 6.7 Assessment of Fraunhofer InHaus Center

Laboratories simulate **real-life environments** for testing and evaluating products and solutions under almost real conditions of use. **Pluridisciplinarity** is guaranteed through the huge variety of research institutes as stakeholders, a close link to higher education institutions and the large number of companies from different areas, which participate as partners. In recent documents the center describes the inHaus method as **Open Innovation in Living Labs**. The evaluation by its director reflects this holistic and complete approach in all fields.

Magic Box (SD 2005) – Campus Montegancedo (UPM) (case study R11)

The objective of Magic Box is to offer a **multidisciplinary laboratory for research and training on sustainable buildings, renewable distributed generation and intelligent control**. The goal is to facilitate the use of an SD prototype as a research lab and demonstration site for solar energy in buildings and the possibilities of electricity demand management.

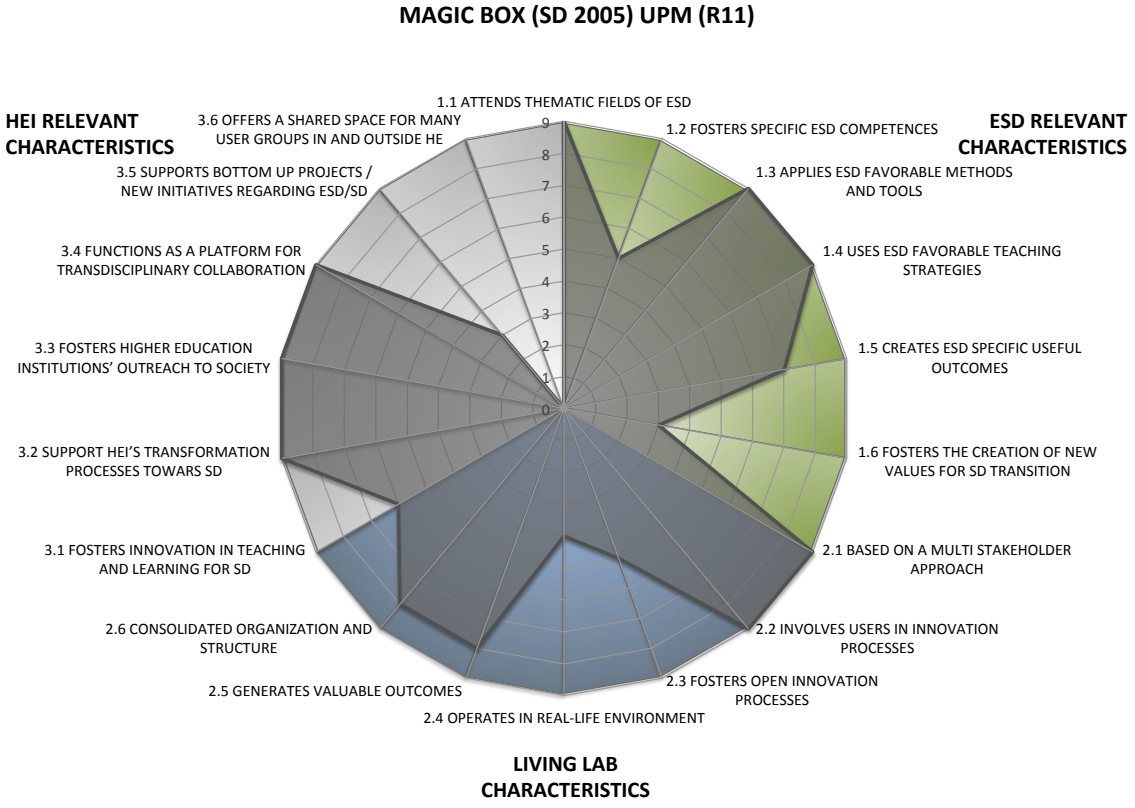


Figure 6.8 Assessment of Magic Box (UPM)

Magic Box is mainly used as an ordinary laboratory-like monitored prototype building for technological research and related teaching and knowledge dissemination activities. It is not open to other users, but does create a real-life environment to a certain degree, as reflected in the assessment by its project leader.

Les Grands Ateliers (Grenoble) (case study R07)

Les Grands Ateliers is a **large-scale construction facility for experimental building activities**, founded in 2001, financed by Region RhónAlpes, and developed by a group of higher education institutions from Rhône-Alpes.

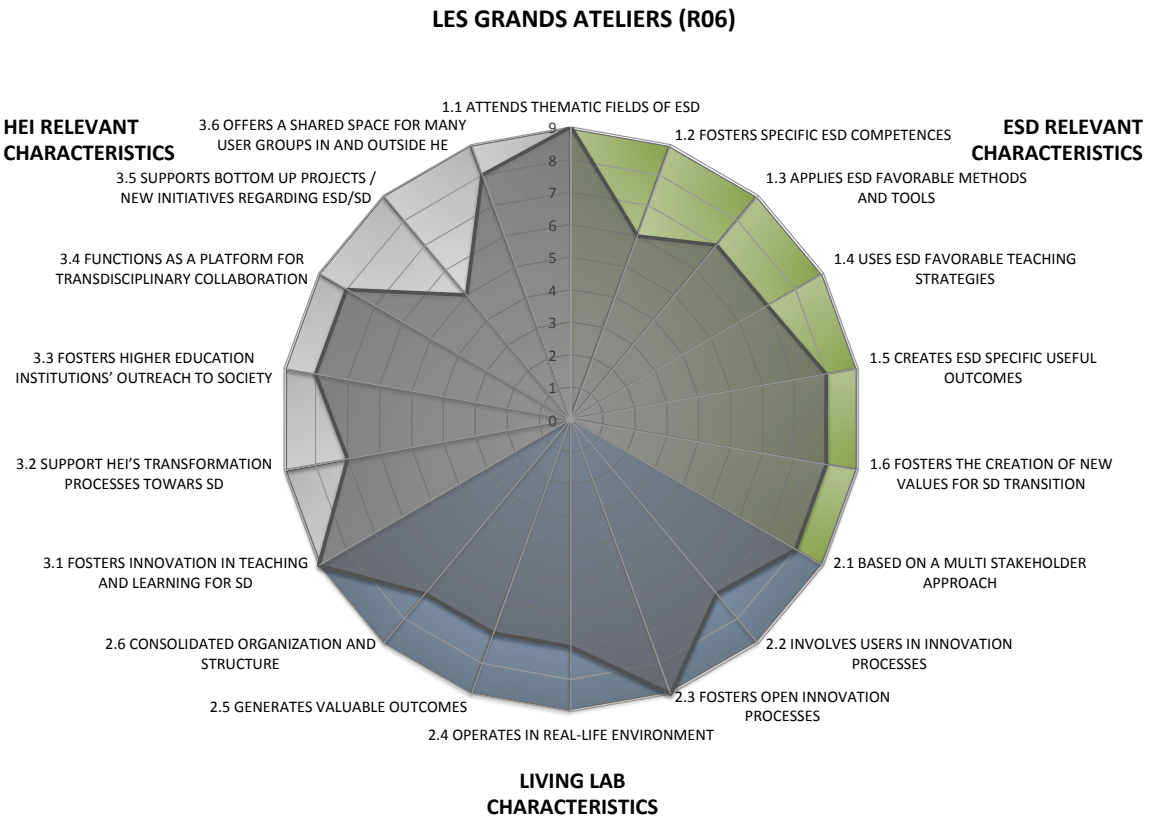


Figure 6.9 Assessment of Les Grands Ateliers (R06)

Experimentation, **co-creation and innovation** take place during the development of projects at Les Grand Ateliers, like the Solar Decathlon Europe prototype buildings Armadillo Box (SDE 2010)[112] and Canopea (SDE 2012)[113], built by student teams of ENSA Grenoble. Although active user participation is limited in this stage of the projects and generally no active **user-centered research or user co-creation** is possible, general user needs are analyzed and also societal challenges like sustainable living in cities or vertical farming and energy self-sufficiency based on renewable energies are addressed during this phase.

[112] http://www.ines-solaire.org/france/DT1309170462/page/Armadillo-Box.html (accessed July 2015)
[113] http://www.sdeurope.org/downloads/sde2012/ (accessed July 2015)

PASaPAS (UPC) (case study R16)

PASaPAS is the **2012 Solar Decathlon Europe prototype** of UPC, developed by a student team of its School of Architecture ETSAV. **From 2015** the project is located at the Les Planes neighborhood of Sant Cugat del Vallés, near to the ESTAV campus, as a **community lab and place for meeting and organizing neighborhood initiatives**, e.g. related to energy poverty, energy efficiency and public space.

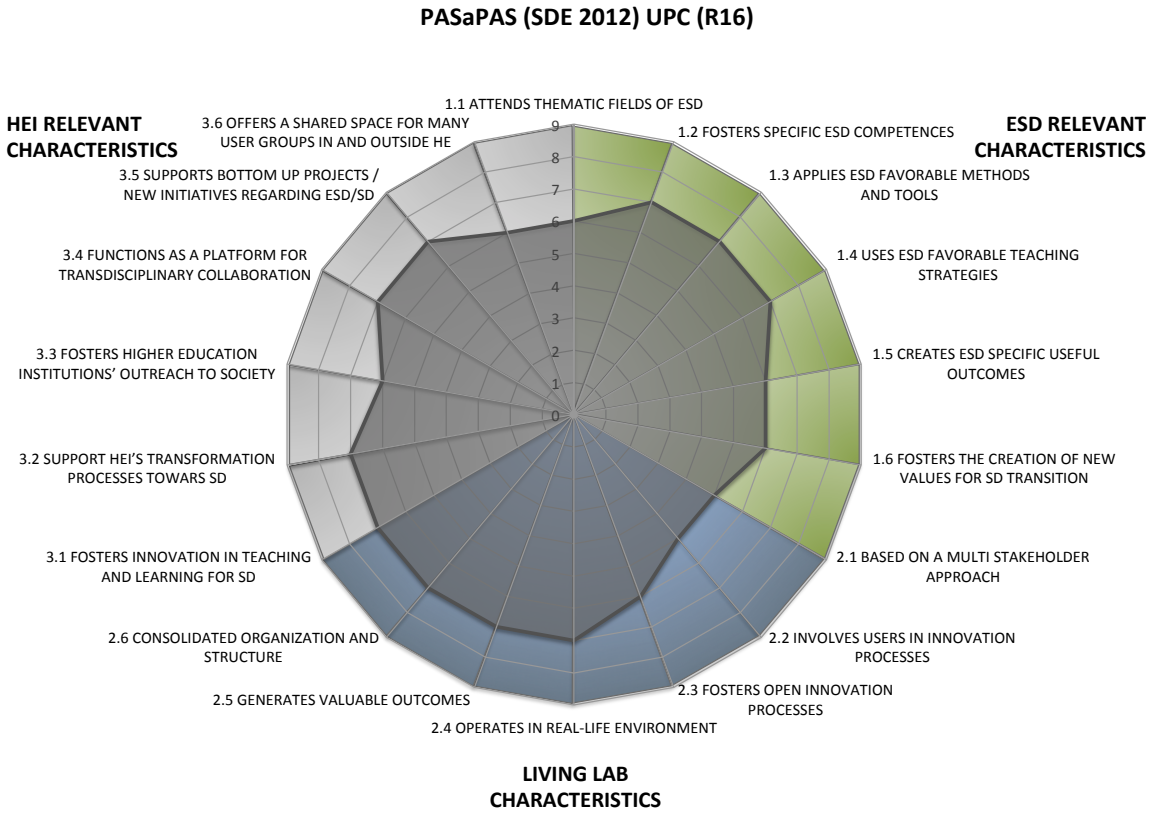


Figure 6.10 Assessment of PASaPAS (UPC) (R16)

In order to collectively improve the quality of life of citizens, the project has implemented a process of monitoring, intervention and evaluation in the **real-life environment** of the neighborhood through a pluridisciplinary approach, with the citizens as active participants of the project. **User-centered research** through user surveys, observation and monitoring forms part of the process, **co-creation and innovation** activities are basic underlying principles and considerable **outcomes** could be generated in a relatively short time.

Ressò (UPC) (case study R17)

Ressò is the **2014 Solar Decathlon Europe prototype** of UPC, developed by a student team of its School of Architecture ETSAV. **From 2016** the project will be located at the Sant Muç neighborhood at Rubí (Barcelona), near to the ESTAV campus, as a **neighborhood co-housing facility for meeting and organizing neighborhood initiatives.**

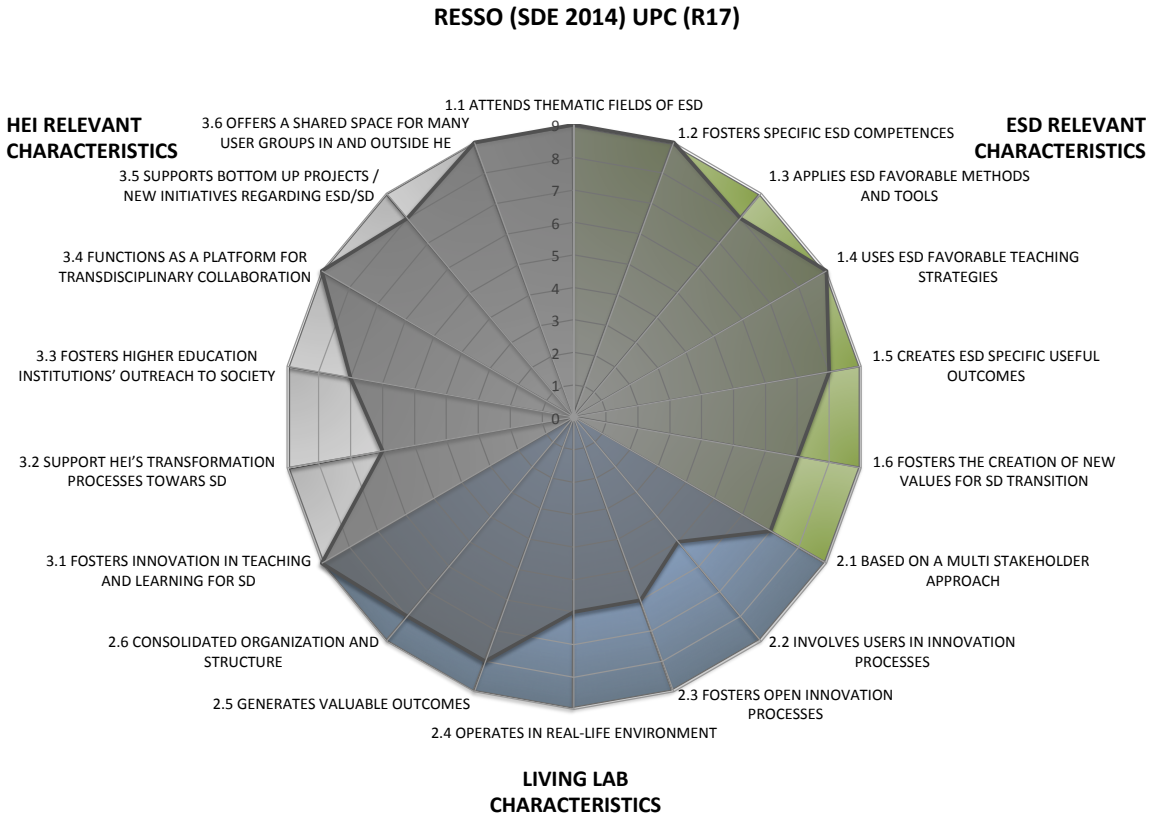


Figure 6.11 Assessment of Ressò (UPC) (R17)

Ressò is a **unique neighborhood co-housing facility,** which activates synergies among neighbors, administration, university and private companies through a public-private-people partnership (PPPP), in order to collectively improve the sustainability of the community i.e. in the fields of mobility, energy and social innovation. This project is about monitoring, improvement and the evaluation of sustainability related parameters in the **real-life environment** of a community through a pluridisciplinary approach, with the user as active participant in the project. **User-centered research** and **co-creation and innovation** activities will be applied.

Comparison between Ressò (UPC) (case study R17) and Magic Box (UPM) (case study R11)

A direct comparison can be made between two or more projects in order to evaluate the relative strengths and weaknesses of each of them.

In the case of Ressò and Magic Box, it can be stated that Magic box seems to foster less specific ESD competences and contributes less to the creation of new values for SD transition. Magic Box does not offer shared space for many user groups from in and outside HE and supports only in a limited way bottom up projects and new initiatives regarding ESD/SD.

This is due to its function as a technological laboratory for industry research, with limited use as Living Lab, although it involves users in innovation processes and is based on a multi stakeholder approach according to its responsible.

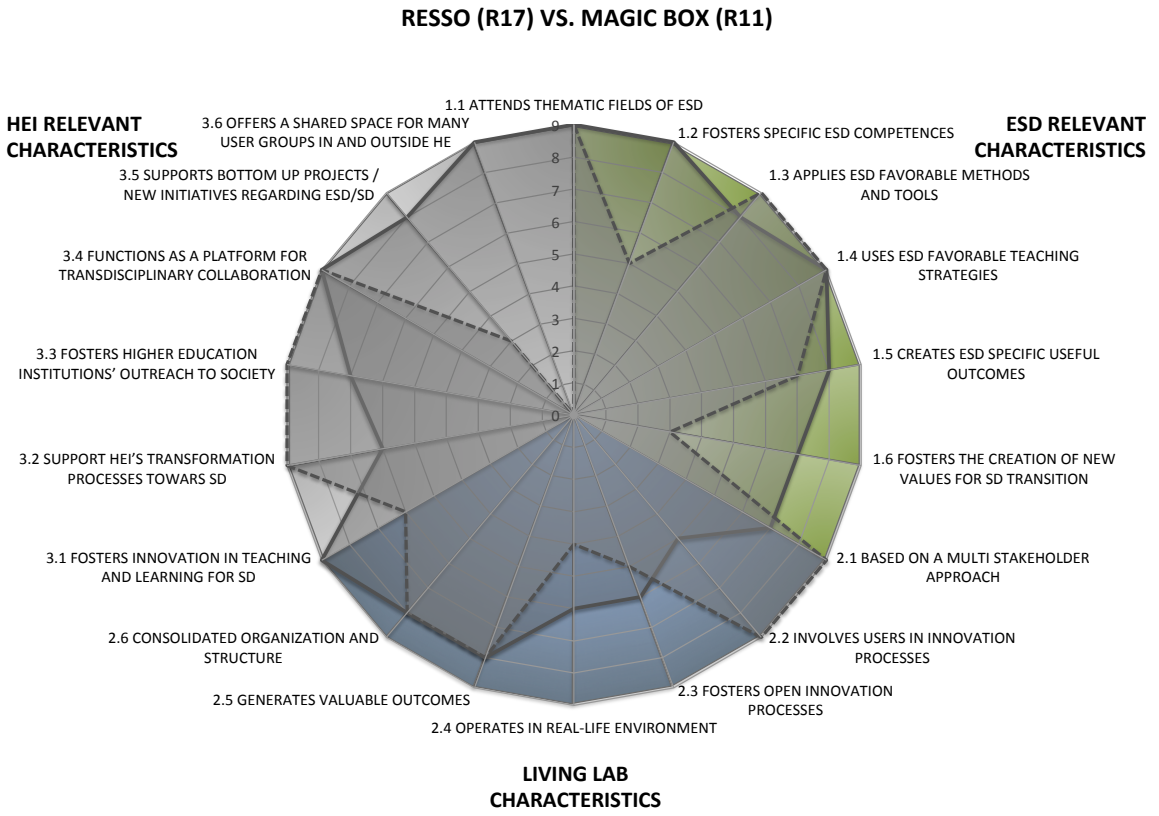


Figure 6.12 Comparison Ressò (R17) vs. Magic Box (R11)

Ressò on the other hand, offers the mentioned shared spaces to user groups in and outside HE, as its concept is that of a neighborhood facility which is open to different groups and which aims to generate synergies and social innovations, something that is clearly reflected in the evaluation by its project leader.

6.6 Summary and conclusions

A **3-step classification tool** for Architecture Living Labs related to ESD in HE has been presented in order to allow a detailed analysis and comparisons of projects at different levels.

The **first step or *basic differentiation*** relates to the mapping of Living Labs regarding two parameters: **Industry/Research versus University/Society** based stakeholders, and **Disciplinary versus Holistic approach to sustainability** identifying **four different categories**, namely

- University/Society based technology oriented Living Labs
- University/Society based holistic Living Labs
- Industry/Research based technology oriented Living Labs
- Industry/Research based holistic Living Labs.

This allows the distribution of projects over 9 sectors of a two-axis graph, differentiating them according to two basic parameters and showing tendencies for the prevalence of certain types of profiles among the 20 selected case studies of Architecture Living Labs.

The **second step or *generic classification*** of Architecture Living Labs identified and applied 6 basic benchmarking parameters in order to assess the fulfillment of specific Living Lab characteristic of a project. A **scoring system** has been established and a graphic representation tool has been designed in order to visualize the **individual and global performance** of a project.

The tool has been **applied to all 20 case studies** of recent Architecture Living Labs, integrating the outcomes into their individual project data sheets (Appendix II). The **individual ratings** and the resulting **overall ranking** have been discussed, detecting specific profiles, similarities and differences between projects.

The **third step or *holistic representation*** of Architecture Living Labs consists of an **holistic benchmarking** regarding their **ESD related activities** as well as their contribution to **HEI's transformational processes** towards SD (chapter 6.5). For the **3 main areas of benchmarking** a set of six **basic benchmarking parameters** have been defined with **3 sub-indicators** each, resulting in a total of 54 indicators (chapter 6.5.2).

In order to raise the necessary data by project leaders, a simplified **online inquiry** has been used in order to receive their evaluation of the **main 18 benchmarking parameters**.

A **holistic graphic representation tool** has then been developed in order to visualize **strengths and weaknesses** of individual projects. The tool has been applied to 5 projects and results have been discussed.

The presented **tools for differentiation, classification and representation** of Architecture Living Labs contribute to a **deeper understanding** of the character and potential of these type of projects, allowing the **assessment of** existing ones, the **evaluation of progress** over time, and can even be used as a **planning tool** for new projects. Through this developed approach, Living Lab characteristics and ESD related characteristics may be assessed together in order to foster the approach of **Architecture Living Labs for ESD within the transitions processes of HEIs towards SD**.

7 CASE STUDY: LIVING LAB LOW3 (UPC)

Chapter 7 describes the case study of the LOW3 prototype solar house of UPC BarcelonaTech, and the process of its development, implementation and evolution into Living Lab LOW3 during the period 2010-2015. It analyses the applied Living Lab concept, its innovative approach to teaching, and its specific contributions to ESD at the ETSAV School of Architecture (UPC), applying the 3-step differentiation and classification methodology developed in chapter 5, and using educational research methodology, namely action research, in order to evaluate outcomes and results.

7.1 Introduction

The LOW3 prototype solar house of UPC has been designed and built between 2008 and 2010 and converted and operated as a *Living Lab for sustainable architecture and lifestyle* since 2010 at the ETSAV campus at Sant Cugat del Vallés (Barcelona) under the responsibility of the author.

The related educational and managerial experience within the institutional framework of UPC, together with 5 years of action research approach to innovation in pluridisciplinary, experience based sustainability education, constitute the inspirational and undoubtedly personal background of this work. In this context, from the start in 2010, the following questions have motivated research and action:

- What are the main factors, which distinguish a Living Lab learning process from a more traditional learning experience, and how can this contribute to a holistic, experience based and transformative learning experiences?
- How can an Architecture Living Lab be managed, operated and maintained as a platform for teaching and learning?
- How can the Living Lab approach contribute to reinforce sustainability as a holistic paradigm within the professional and private self-understanding of students?
- Which experimental formats of teaching and learning at Living Lab LOW3 have the strongest impact on the overall learning experience in the field of sustainable architecture and lifestyle, and ESD in general and therefore can be recommended for similar initiatives?

This chapter, based on the case study and experience, tries to give answers to these questions from a practical and even personal point of view, complementing the conceptual approach to Architecture Living Labs (chapters 3 and 5) and research on their use in higher education for ESD (chapters 2 and 6).

Based on an **action research approach** and using educational research methodologies, like mixed method research, participant surveys, personal field notes and similar approaches, this chapter is structured in the following way:

Chapter **7.2 describes Living Lab LOW3 in general terms**, regarding its origins, objectives, applied methodologies and organization in the context of the ETSAV campus at Sant Cugat del Vallés.

Chapter **7.3 focuses on the educational concept of Living Lab LOW3**, through a description of its academic activities, as part of a **new, emerging educational ecosystem** at ETSAV, which links formal teaching to informal learning and a whole series of initiatives within an innovative, non-formal learning environment at the campus.

Chapter **7.4 offers a holistic impact evaluation of the Living Lab LOW3** concept on teaching ESD, using educational research methodologies, namely **action research**, for a mixed-method, qualitative and quantitative analysis and evaluation of specific living lab teaching and learning activities.

Chapter **7.5 applies the 3-step classification tools developed in chapter 6** in order to classify and compare Living Lab LOW3 with other Living Lab initiatives and draws conclusions about the specific character of the project and its specific contribution regarding ESD in HE.

Chapter **7.6 offers conclusions based on the specific Living Lab LOW3 experience** as a platform for research and teaching, fostering ESD in higher education.

7.2 General description of Living Lab LOW3

7.2.1 Background of Living Lab LOW3

The UPC can be considered a pioneer university, which founded its own environmental office and program in the early 2000's, developing specific plans for sustainability in the fields of management, education and research. The Catedra UNESCO Sustainability Chair, the "Pla Mediambient" program and the CITIES office fostered sustainability education and projects, supporting bottom up initiatives by students, faculties and employees at different campus locations of the UPC.

From 2003 to 2009, the UPC has formed part of the EESD-Observatory (Engineering Education for Sustainable Development), a collaboration of three European Universities (UPC, TU Delft and TU Chalmers), organizing biannual EESD conferences. The 2004 Barcelona Declaration of the EESD network stated a commitment of the participating institutions towards education for sustainable development.

Today the University Institute for Research in Science and Technology for Sustainability (IS.UPC) runs several Master and PhD Programs for Sustainability at UPC with a strong focus on research in collaboration.

The ETSAV School of Architecture

In the area of architecture, the ETSAV School of Architecture at Sant Cugat del Vallés can be considered a pioneering institution in understanding its campus and buildings as a laboratory to learn about energy efficiency in buildings, but also its community as an important stakeholder for a broader approach to sustainability regarding its socio-economic environment.

One important initiative has been carried out at ETSAV under the project title "UPCO2", creating an energy monitoring system for several campus buildings of UPC and introducing measures for the effective reduction of energy and water consumption through optimized building management and control. One of the outcomes has been the SIRENA Resource Consumption Monitoring System.

Another important impulse for introducing sustainability in education at ETSAV has been the foundation of PAUS – Platform for Sustainable Construction as a teaching module based on participation in experimental construction at the campus, and also related to projects and exhibitions outside the campus.

LOW3 - Solar Decathlon Europe Competition 2010

Solar Decathlon is an international competition for 20 selected universities to plan and build prototypes of energy self-sufficient solar houses. In 2008 a first ETSAV team under the lead of the author started the development of the first **prototype solar house LOW3** at the campus in order to participate in the Solar Decathlon Europe[114] 2010 competition in Madrid (Masseck 2011b).

The LOW3 project[115] (2008-2010) demonstrated over a 2 year period the importance and impact of a **new way of education in architecture**, based on the development and construction of a prototype house at the campus with a high degree of team self-organization, individual responsibility, and a strong link between teaching and research.

More than **100 students** participated in the project during 2 years and 50 team members constructed, operated and presented the prototype at the competition in June 2010 in Madrid with a mix of Bachelor and Master students and multidisciplinary collaboration between architects and engineers.

One of the main qualities of the project is its interdisciplinary approach between architecture, technology, environmental sciences, marketing and communication with a student team running a partly **self-organized team office** within the school of architecture. One of the biggest challenges in this context was the conversion of a university campus into an experimental building site with all the academic, legal and professional consequences.

Students had to assume considerable responsibility and accountability during the different phases of the 2 year project, developing **transversal skills and competences** like working in a

[114] http://www.sdeurope.org
[115] http://www.low3.upc.edu/eng/low3_sde_eng.html

complex, pluridisciplinary, conflict solving and decision-making team, as well as using communication skills towards collaborating entities and society in general.

A total of **3 different "generations" of students** participated between 2008 and 2010, from the design stage to construction, competition and exhibiting in Madrid in June 2010, learning continuously about sustainable architecture and related technical, environmental and economic issues within an international multicultural context. This experience has been transformational for them as future professionals in the building sector, and contributed to the improvement of many generic, ESD specific and interpersonal competences.

After the competition in Madrid in June 2010 the house was dismantled and returned to the campus at Sant Cugat, awaiting its future use as a Living Lab.

7.2.2 Living Lab LOW3 - implementation

Once the official competition had finished, an exhausted team of students returned to university in order to continue with their study program, which was temporarily interrupted due to their full-time dedication to the LOW3 project. At the same time, plans for rebuilding the house at the ETSAV campus were developed by the author in order to convert LOW3 into an experimental infrastructure at ETSAV (Masseck 2011a).

Management, funding and stakeholder participation

At the start of its ***post-competition life*** LOW3, as many other Solar Decathlon projects, lacked all types of resources. Voluntary student collaborations, institutional interest and media attention had suddenly diminished, accompanied by the exhaustion of administrative staff and collaborators due to the complexity and intensity of the competition experience.

A project like LOW3 at a university campus is a complex infrastructure that needs **regular funding** for its installation, maintenance and management. Stakeholders such as local, public administration and private companies are ideal partners to participate conceptually and financially in such an infrastructure in order to convert it in a place for teaching, learning and innovation within university, but also for society in general.

These collaborations can be based on **public private partnerships (PPP)** or university-industry collaboration agreements. Nevertheless, in a multi-stakeholder approach, organizational difficulties can arise regarding university regulations (access, insurance, responsibilities), operation and maintenance costs, leadership, and many other aspects.

LOW3 received 2010/11 public funding for post-competition research and demonstration, and closed two university-industry collaboration agreements, which generated the necessary resources for its **reconstruction and operation** at the campus. Later on, an international **teaching innovation program** (KIC InnoEnergy Learning Module 2012) and UPC support program for innovation in teaching (FPC – *Innovació docent*) allowed working on the Living Lab concept and implementing experimental teaching and learning formats at Living Lab LOW3. International recognition (European Solar Prize 2013) contributed to a higher visibility and institutional integration of the project.

All management and operation activities and main educational innovation initiatives have been directed by the author from his position as head of the Solar Research Unit CISOL at the Vallès School of Architecture.

Fig.7.1 shows the initial stakeholder network at the start of the Living Lab LOW3 project in 2011, showing a mix of public and private stakeholder

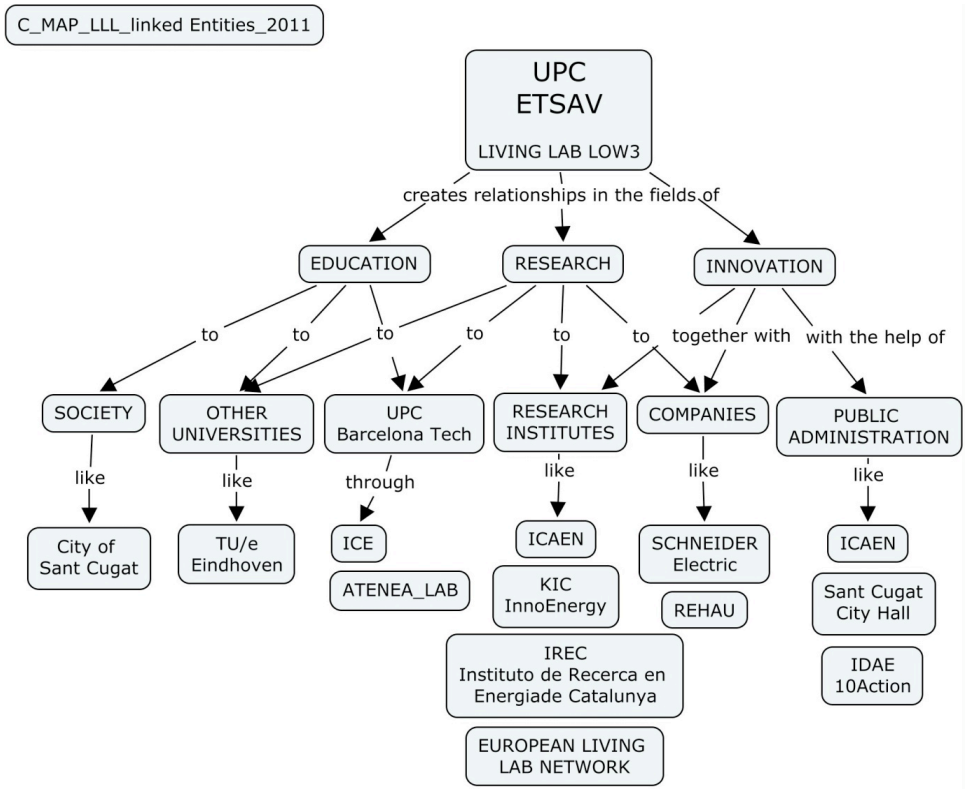


Figure 7.1: Multi stakeholder context of Living Lab LOW3 at its start in 2011

Collaborations varied during the last 4 years, some stakeholders left and others joined in over that time. Nevertheless it shows that Living Lab LOW3 allowed the creation of a growing network of public and private stakeholders, which are related to some degree to the project, financing its operation, benefiting from its infrastructure, participating in its activities or collaborating in specific projects.

At the time of writing, Living Lab LOW3 can be considered a consolidated infrastructure at the ETSAV campus with regular use by different student or interest groups as well as regular teaching and outreach activities.

7.3 Educational concept of Living Lab LOW3

General considerations

The changing socio-environmental and socio-economic scenarios of the last decades resulted in the decline of the architect's role in our society due to the specialization and concentration processes within the building sector. Real estate developers and engineering companies took the lead and the profession suffered the **loss of clear definition** of its competences.
Nevertheless the necessity for a holistic view on today's complex socio-economic and environmental conflicts and their possible solutions, seem to be a great opportunity for re-inventing and re-enforcing the role of **architects as key persons** within these complex social, political and economic processes. With a broad knowledge in different disciplines, advanced communication skills as well as detailed technical expertise, architects could evolve as promoters, mediators and **experts for the transition process** towards more sustainable architecture and urbanism within a more sustainable society. (Herzog 2007)

7.3.1 Living Labs in architectural education

Education at schools of architecture must attend to the mentioned demand for a **new profile for architects**, integrating and fostering corresponding **SD competences** through new learning methodologies, tools and concepts. (EDUCATE Project Partners 2012)
On the other hand a newly strengthened **social responsibility** of university towards society in the development of innovative solutions for our **environmental, social and economic conflicts** must lead towards new processes in teaching, research and technology transfer based on a strong **interaction with their local and regional communities** and society in general. (Cortese 2003)

Learning processes for architects are traditionally linked to real projects as well as real-life experience through visits and the direct perception of materials, space, light and function of architectural, urban and landscape projects.
These same **experience-based learning approaches** might be useful regarding new **sustainability-related fields of knowledge** like low energy buildings, renewable energies systems, environmentally responsible materials, systems and concepts, and sustainable architecture, urbanism and life style in general.
On the other hand, priorities for knowledge, skills and competences, must be defined in a continuous process of **critical reflection** on real world problems, scientific and technological advances, as sustainability is a **changing paradigm** in constant need of redefinition. (ENHSA 2007)

Within this context, **laboratories** are already established as places for teaching and research on materials, construction technologies, as well as specific aspects like light, HVAC, building simulation or modeling and representation, with a link between theoretical knowledge and experimentation.
As a step further, **real-life environments like Living Labs** may integrate experience-based, user-centered research and teaching concepts as a basis for holistic learning and innovation with a direct relationship to society and its socio-economic and socio-environmental challenges.
Living Labs in Architecture therefore seem to make a positive contribution to architectural education in its approach to sustainability. (Masseck 2011a)

7.3.2 Living Lab LOW3 – concept

LOW3 was reconstructed in 2011 and renamed ***Living Lab LOW3 – Laboratory for sustainable architecture and lifestyle*** at the ETSAV Campus at Sant Cugat del Vallès (Barcelona) with the objective of establishing an open platform for collaboration with companies, and an exploration of experience-based concepts for teaching, research and innovation activities.

Living Lab LOW3 adds value to the academic offer at UPC-Barcelona Tech through its innovative transdisciplinary educational programs, transmitting **experience-based knowledge** about integrated energy design in architecture and a **holistic approach to sustainability**.

The concept of Living Lab LOW3 is influenced by the concept of **user involvement** in research and innovation, derived from the definition of Living Labs, as well as the **co-creation** and **open innovation** in **real-life settings** through a **multi stakeholder approach** (academia, companies and research entities but also local administration), understanding both students, researchers as well as citizens as the "users" of this newly generated platform. (Masseck 2014)

The concept of Living Lab LOW3 is that of an **activities platform** with a **participatory approach** to teaching and learning based on a prototype solar house, offering its spaces, its equipment and its infrastructure to diverse user groups from both inside and outside the UPC.

Teaching and learning activities take place in parallel with research projects and outreach activities in order to create **synergies between sectors, people and disciplines**. Finally, Living Lab LOW3 is also a place for the networking of people in order to engage in new sustainability projects and initiatives, **fostering the human factor** behind these activities.

Living Lab LOW3 today forms part of a **new, emerging educational ecosystem** at ETSAV, which links formal teaching with informal learning and established educational courses to a whole series of outreach initiatives supported by non-formal learning environments at the campus.

7.3.3 Living Lab LOW3 – action research

Living Lab LOW3 has been an **educational research project under continuous development** since January 2011. During almost 5 years of its existence, a series of different innovative teaching and learning activates have been implemented. The overall objective has been to evaluate the potential contribution of an *Architecture Living Lab* to a holistic trans-disciplinary education in sustainability through the implementation of new teaching formats, methods and tools, the link between formal and non-formal learning, the exploration of the personal learning environments of participants and the synergies between teaching, research and innovation.

These activities must be understood as part of a **continuous action-research approach**, which has undergone an evolutionary process until the present date of writing.

In the same way as the activities themselves, the **evaluation process** has been experimental, using tools such as student surveys, knowledge questionnaires, personal interviews, video documentary, as well as diary-like documentation of the process, in order to record, analyze and compare the results. (Masseck 2013)

7.3.4 Living Lab LOW3 – activities

Fig. 7.2 shows chronologically the different steps for the implementation and operation of LOW3 as Living Lab at the ETSAV campus and the main developed activities during the last 5 years.

Since 2011 **3 regular Living Lab LOW3 courses, 6 innovation seminars, 2 international sustainability seminars, 1 house occupation experiment, 5 open doors days and around 25 educational visits** have taken place at Living Lab LOW3, with links to different Master and PhD Programs both inside and outside the UPC and the ETSAV undergraduate program.

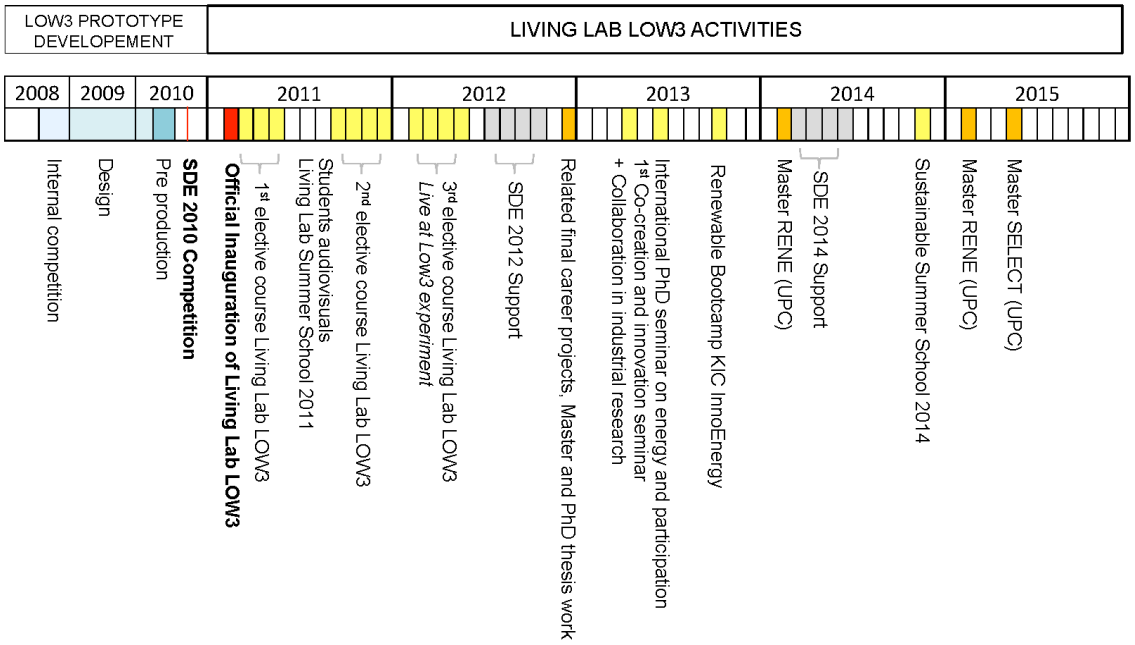


Figure 7.2: Living Lab LOW3 activities 2011-2015

Additionally more than 30 specific events took place that opened up the house to user groups to disseminate knowledge, to offer its spaces for events or to allow small-scale teambuilding activities for the academic community.

Main activities since 2011:

- **Living Lab LOW3 course 2011:** re-construction, installation works, analysis, first measurements of the LOW3 prototype solar house at the campus
- **Living Lab LOW3 course 2011/12:** installation works, bioclimatic measurements, holistic evaluation, knowledge dissemination
- **Living Lab course 2012: LIVE AT LOW3 experiment** – activity based on user-centered research: house occupation with 2 students during 2 weeks and holistic evaluation of their lifestyle and impact through the participating student team. Course documentary https://www.youtube.com/watch?v=_IK88J21-2g

- **Related final career projects, Master and PhD thesis work:** Natural ventilation in buildings (2011), The house management system of LOW3 (2012), Personal Learning Environments (2012), Grey water recycling (2012) and Living Labs in Architecture (2012)
- **ETSAV - 1st co-creation and innovation seminar:** co-creation and innovation seminar giving support to student projects and initiatives related to sustainability (2013)
  Seminar documentary: https://www.youtube.com/watch?v=XpYzjMziHyk
- **Collaboration in an industrial research** project on concentrated solar power systems and energy storage in buildings (2013)
  Information: http://www.livinglab-low3.blogspot.com.es/2013/07/new-collaboration-in-field-of-renewable.html
- **Living Lab Course at HfT Stuttgart:** collaboration with home+ project team of HfT, developing Living Lab concepts for the home+ prototype house. (2013)
- **International PhD Seminar on Energy and Participation**: 3-day co-creation and innovation seminar with PhD Students from eastern universities within the International Seminar on Sustainable Energy Technology of IS.UPC. (2013)
  Course documentary: https://www.youtube.com/watch?v=ldZSQHRnNBA
- **Living Lab activity "Zero Home":** Evaluation of the energy consumption profile of LOW3 and exploration of specific user patterns for the design of an energy storage and management concept for up to 100% grid independence (ZERO HOME project)
- **Master RENE (UPC) – Innovation and Co-creation Seminars 2014 and 2015** for international students of the Master "Renewable Energy Systems", KIC InnoEnergy
  Course documentary: https://www.youtube.com/watch?v=gNyzKhuZbY4
- **Master SELECT (UPC) – Innovation and Co-creation Seminars 2015** for international students of the Master "Environomical Pathways for Sustainable Energy Systems", KIC InnoEnergy
  Information: http://www.livinglab-low3.blogspot.com.es/2015/05/innovation-seminar-at-living-lab-low3.html
- **Sustainable Summer School 2014: "Creative Transition towards Sustainability"** International PhD Seminar on holistic transition approaches to sustainability, together with Wuppertal Institute, ecosign, UWID
  Course documentary: https://vimeo.com/126891567
- **MOOC concept development for a "Virtual Living Lab course"** related to the physical Living Lab LOW3 – in preparation (2015)
  Documentary: https://www.youtube.com/watch?v=vCe37LAjwoo
- **Several other activities related to teaching, consulting and dissemination** like educational visits for high school students, professionals or open doors days for the general public, with more than 1200 participants
  Documentary educational visits: https://www.youtube.com/watch?v=1AmKqJMU6ME

Since 2012 all activities have been documented on the Living Lab LOW3 Blog under: **http://www.livinglab-low3.blogspot.com.es**

Appendix III resumes several Living Lab LOW3 activities 2011-2015.

7.3.5 Live-at-LOW3 Experiment

One of the most intensive, experience-based, transformative teaching and learning activities has been the 'Live-at-LOW3' experiment, a house occupation experiment in 2012.

The '**Live-at-LOW3' experiment** was carried out within the elective course "Living Lab LOW3", linked to the Master Program Sustainability (IS.UPC) and the ETSAV undergraduate program.

This teaching and learning concept needed special commitment by the participating students. No regular timetable could be guaranteed during the course. The **house-occupation experiment** has been a holistic approach to **user-centered research**. A pair of selected students evaluated and tested the prototype solar house during 14 days with the participating course students preparing, accompanying and evaluating the experiment through the monitoring and evaluation of the **inhabitant's lifestyle** with a holistic view on housing, consumption, food and mobility.

This course had a **transformative effect** on its participants, as parallel to theoretical knowledge about sustainable lifestyles, the related experience-based learning shows to be highly effective.

The experiment included:

- Monitoring **energy consumption** (daily consumption, relation to daily activities, comparison with solar production)
- Assessing **water consumption** (grey water recycling, dry toilet, water saving measures)
- Measuring **waste production** (daily production, type and weight)
- Assessing **indoor comfort** (day and night comfort in the house, privacy, air quality, noise)
- Reporting about **food habits** (local market, own vegetable garden and even 2 hens at the campus)
- Calculating the overall **ecological footprint** of the inhabitants

Results were published in course reports[116], the experiment was filmed and published through a documentary as well as local newspapers, and television showed interest in the experiment and its outcomes[117].

A holistic learning and **user-centered research** process was conducted in order to **evaluate the LOW3 solar house**, its concept, its technologies, and the resulting comfort for inhabitants. A wider engagement of the academic community, as well as society in general, could be achieved through **open door days**, media interest (national and local TV and radio emissions, digital newspapers) and the use of social networks and ICT (YouTube channel for video diary, documentary, live webcam).

The educational experiment was very successful, students evaluated their participation and related learning very positively, although the course was time consuming for all participants and needed certain economic resources. The educational format had to overcome administrative and legal issues and depended on a special personal commitment of all participants, which is the reason why this format could not be repeated since then.

[116] http://www.low3.upc.edu/eng/plataforma_eng.html
[117] http://www.livinglab-low3.blogspot.com.es/2012/10/fin-del-primer-experimento-visc-low3.html#more

7.3.6 The role of Living Lab LOW3 as multi-stakeholder platform

Architecture Living Labs can serve as multi-stakeholder platforms, which connect the academic world with its surrounding - the professional world of architecture and building construction, the productive sector, public administration, and last but not least, society as a whole. Through its experimental character, Living Labs can offer a place to meet, reflect, discuss, learn, explore and develop ideas, concepts and strategies with regard to sustainability in a most holistic way, not only limited to architecture but also considering the lifestyles adopted by society which include existing consumption and production models, political and economic issues, as well as social processes and innovations.

Platform for interchange between the professional and the academic world of architecture:
Living Labs can have a role as platforms, which bring together professional associations interested in life-long learning and additional professional qualification programs, and the university (students, teachers, research groups) in order to create synergies between the academic and the professional world of architecture and building construction.

Example Living Lab LOW3:

- AUS – Architects for Sustainability Association – Visits to Living Lab LOW3, special events
- Visit of the Chamber of technical architects of Catalonia (CAATB)
- Visit of professionals of building maintenance

Links to the production sector of the building industry:
Another component would be the linkage of companies to these type of platforms allowing synergies in the knowledge dissemination about materials, products or services, within an environment which allows critical reflection, in-situ evaluation and as a consequence, a creative approach to innovations through the created synergies.

Examples in Living Lab LOW3:

- REHAU – exposition and support for system evaluation of radiant heating systems and wall-integrated solar thermal collectors
- SOLARLUX – exhibition of products and showroom for clients
- AISLUX – support for further development of building components in the context of a new prototype (SDE 2012 - eco prototype and SDE 2014 - Ressò prototype)
- VGP Valldoreix Green Power – Evaluation of a CPV system connected to LOW3

Links to public administration:
Living Lab platforms can serve to establish valuable relationships with public administrations, allowing collaboration between municipalities and academic institutions in many ways related to knowledge generation and dissemination, consultancy services, formative activities as well as specific project development.

Living Lab LOW3:

- Sant Cugat city administration supported the LOW3 project. Synergies formed indirectly through the following SDE 2012 (eco) project, which has initiated an innovative participatory, energetic refurbishment process in collaboration with the city administration and a specific neighborhood looking for an integrative approach to battle energy poverty through a multi-stakeholder approach with a strong social component.

Living Lab LOW3 has contributed to this project through the use of its infrastructure and the participation in its co-creation workshop, giving support to this innovative project.

Links to society:
An important outreach of a Living Lab infrastructure can be the direct impact on society in terms of knowledge dissemination and critical reflection, offering a place for learning and experiencing different aspects related to a more sustainable lifestyle in general like resource consumption in our buildings, the environmental impact of materials, alternative forms of living such as co-housing, or the impact of food and water consumption.

Living Lab LOW3:

- Live-at-LOW3 experience with its dissemination to the general public
- Open-doors day of Living Lab LOW3
- Educational visits for high schools
- Open-house Barcelona activities

Links to the academic community:
Living Lab infrastructure can also serve as a place for meeting, working and innovating for all kind of groups of the academic community (and beyond).
Living Labs can be platforms which generate synergies and allow the creation of new initiatives e.g. for HE transition projects towards SD, or community outreach projects, organized by student teams or even administrative staff. This approach reflects the idea of Living Labs as "Transition arenas" e.g. for SD transition of HEIs. (see chapter 5.2.2)

Living Lab LOW3:

- Served as meeting and working space for SDE 2012 and SDE 2014 projects
- Served as meeting and working space for the (e)co / PASaPAS student driven outreach project

7.3.7 Specific Living Lab characteristics

Diversity of people, activities and methods
Fig. 7.3 shows the complex network of fields of activity, specific projects, areas of knowledge, disciplinary, transdisciplinary and ESD related initiatives, as well as the corresponding format, means and methods, and also the types of outcomes generated.

This diversity of activities related to one single platform, allows the creation of synergies between actors, programs and projects, generating the necessary momentum for all types of innovations, technological innovations, social innovations or innovations related to teaching and learning activities.

Stakeholders have the opportunity to participate in a community of users beyond established academic structures, with transversality from high school students up to senior researchers. The resulting networking effects are difficult to track and can only be identified through being part of the network, through conversations with people, and observation of how new initiatives and collaborations start.

In this sense Living Labs can be seen as ***social ecosystems*** within the specific context of university and with a strong link to the surrounding socio-economic context, fostering the creation of **transversal educational communities**.

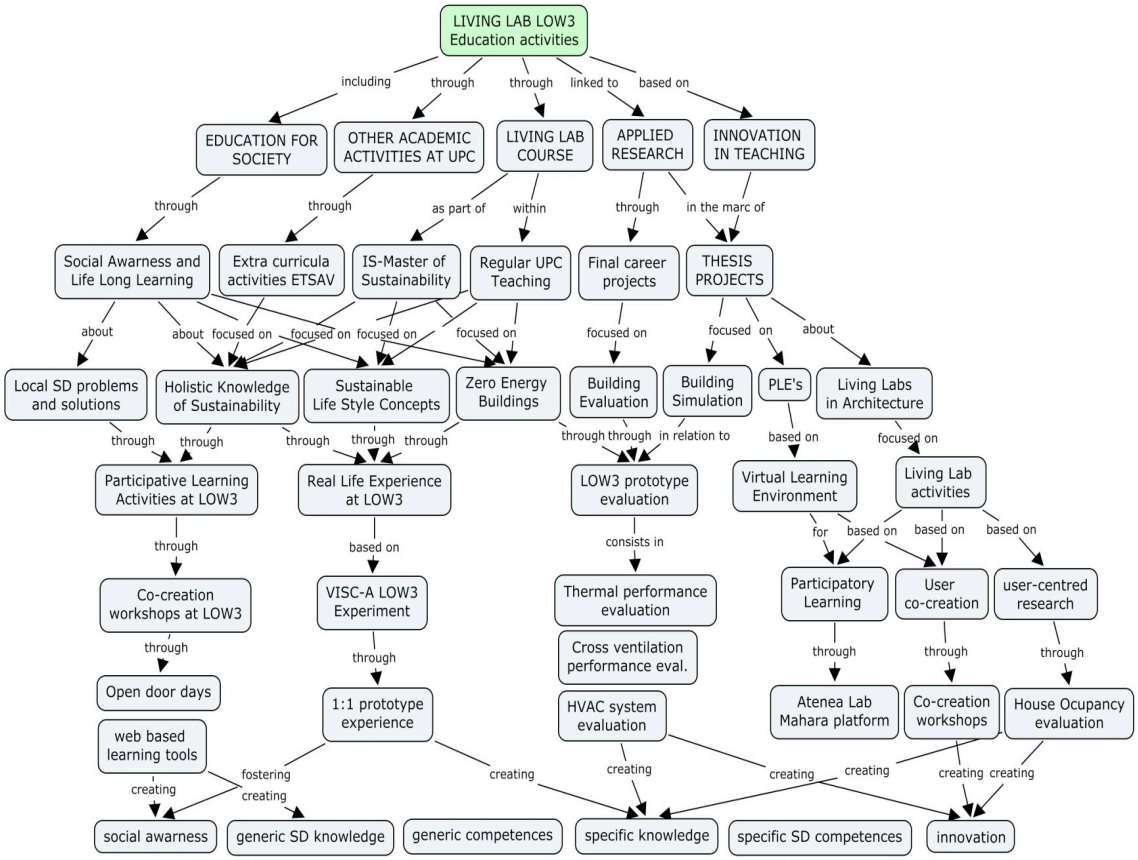


Figure 7.3 Educational activities map Living Lab LOW3

Resource intensity of the Living Lab approach (LLA) in Architecture

The infrastructure of Living Labs in the form of prototype buildings is generally resource intensive with regards to construction, operation and maintenance as a physical place for teaching and learning as well as research and innovation. Even if the initial costs are covered through specific financing e.g. within a competition like Solar Decathlon Europe or through companies, during a Living Lab's lifecycle general services of maintenance, equipment and administration are necessary beyond resources for each specific Living Lab activity.

This makes them comparable to experimental laboratories in HE, with a need for a regular budget to cover consumables, equipment and maintenance in general.

On the other hand Living Lab infrastructures could draw from a ***virtualization*** **of teaching and learning formats** and at least partially convert into ***virtual Living Labs***, allowing the remote use of its infrastructure and partially transfer the learning concept into the virtual space with a community of learners and stakeholders connected remotely.

7.4 Evaluation through Educational Research

The objectives of the educational research activities linked to Living Lab LOW3 are the analysis of the developed Living Lab concept, the applied methodologies and tools, and the outcomes achieved in the field of education for sustainable development (ESD) in order to evaluate the success of the initiative and to contribute to a more general understanding of how Living Labs can foster ESD in the field of architecture.

7.4.1 Relevance of educational research regarding Living Labs in architecture

A series of recent developments give relevance to the research on Living Labs in architecture as new tools for a holistic ESD:

- **A new educational reality,** with redefined objectives in higher education based on competence-based learning (see chapter 2.2) and a more transdisciplinary approach
- **A new knowledge reality**, with a need for acquisition of new knowledge regarding specific subjects like low energy buildings, low-impact building materials and related energy efficient technologies (see chapter 2.3)
- **A new social reality** shifting towards participation, constant social innovations and a higher demand for environmental standards
- **A new professional reality** requiring more collaboration among disciplines, the ability to deal with complexity and uncertainty, the understanding of new regulatory standards and laws and new forms of project development processes based on collaboration and negotiation

All these factors contribute to give relevance to the present educational research work in the context of HE and the search for new methodologies, tools and methods for ESD.

7.4.2 Applied research methodology

Living Lab LOW3 is an **experimental project**, which changes over time regarding its activities and interaction with the context. Regarding the underlying research process, a mixture of research methodologies and reasoning are linked to the project:

An **inductive reasoning**, or "bottom up approach" about the phenomena of Living Labs in architecture has first accompanied the plan for converting the LOW3 prototype solar house into a Living Lab at the ETSAV campus at Sant Cugat del Vallès. Through the observation of the process of implementation of LOW3 at the campus and the documentation of arising opportunities for its use in the field of ESD, evidence could be gathered about the usefulness of the project as infrastructure for teaching, learning, research and innovation activities.

This gave place to the application of a **hypothetic-deductive method** of research linked to the project, with the definition of specific hypotheses about the usefulness of Living Labs in architecture and their potential contribution to ESD, which is the hypothesis of this thesis.
These hypotheses are based on the **theory of Living Labs** and specific related experiences regarding processes of research and innovation, as well as learning theory and the **theory of ESD** itself. In order to confirm or reject the hypotheses about the usefulness of the Living Lab approach for ESD, different research methodologies have been applied:
Regarding the inductive reasoning about the phenomena of living labs in architecture, mainly **qualitative research methodologies** have been applied, collecting evidence though observation,

interviews and the analysis of documents which allow the formulation of a hypothesis, conditioned on the specific context and settings, in this case LOW3 as Living Lab at the ETSAV campus.
This first approach to the living lab phenomena in architecture allows identifying patterns and drawing general conclusions, giving place to a second, **quantitative research approach**, which intends to investigate the established specific hypotheses about achieved learning outcomes and contributions to ESD through educational activities of Living Lab LOW3, using tests and surveys. This **numerical approach**, based on statistical results, is clearly limited through the reduced size of the project, with a **limited number of students** and at the same time considerable **diversity of activities and participants**, as well as the experimental character of the project, in constant evolution regarding its methods, tools and activities.

All conducted research can be considered **applied research**, due to its focus on the effectiveness and usefulness of the specific educational practice related to the LOW3 Architecture Living Lab and ESD. **The objective is to utilize results in order to improve practice.**

Within this educational research of Living Lab LOW3, the project has to be understood as part of a complex **ecosystem of an HE campus** with a strong relationship to its socio-economic environment. As a researcher, the author has been actively involved with the participants of each activity.

Summarizing, it can be said that Living Lab LOW3 is an on-going **action research project**, which applies a **mixed-methods approach** consistent with both **quantitative and qualitative research** methods together. **Phenomenological research** has been used, for example in the Live-at-LOW3 experiment, evaluating the specific experience of students living a more sustainable lifestyle in the LOW3 solar house. The tools used are **surveys, questionnaires, semi-structured interviews, personal field notes** and **course diary** amongst other formats of documentation like **pictures, video documentaries** and **personal participant's videos**.

Research question
The underlying **general research question** of this investigation can be defined as the following:

> ***Which role can have Architecture Living Labs in a holistic SD education in the field of architecture and related disciplines?***

More specifically and related to the field experience and Living Lab case study of LOW3, a **second research question** can be defined as:

> ***To which degree have Living Lab LOW3 activities contributed to a holistic SD education at ETSAV / UPC BarcelonaTech?***

This specific question can be further sub-divided into the following **detailed questions** to answer through the present research:

- Which **skills, abilities and competences** can be fostered specifically through a living lab like LOW3?
- What **specific knowledge** can be transmitted through educational activities of Living Lab LOW3?

- How do students/participants **evaluate the Living Lab approach** regarding teaching and learning in the field of sustainability?
- Which **new tools and methods** can be applied in the context of a living lab in order to meet the goal of a holistic ESD?
- How can **PLE ecosystems** of students be broadened and fostered through living labs?

Delimitation of the research

The research is limited to the analysis and evaluation of educational activities related to Living Lab LOW3 from 2011 to 2015, once the prototype had been returned to the campus after its participation in the SDE 2010 event in Madrid. Only activities organized and executed by the author are described.

Initial hypothesis

General hypothesis:

Living Labs in Architecture like Living Lab LOW3 can be efficient tools for teaching and learning regarding sustainable architecture and life style at universities beside their important role as infrastructures for applied research and collaborative innovation between university, companies and society.

Specific hypothesis:

Experience-based learning activities, the use of an innovative and experimental learning environment and the participatory teaching approach of Living Lab LOW3 foster specifically sustainability-related competences of participants, contributing effectively to a holistic ESD.

Design of the study

The different Living Lab LOW3 activities have been used in order to evaluate the outcomes of each of them. A general **documentation and description** of the process of implementation and activation of Living Lab LOW3 at the ETSAV campus is used in order to confirm or reject the general hypothesis.

Regarding the specific hypothesis, **participant questionnaires** for the beginning and end of each living lab course or activity have been developed, according to each type of activity. Some participants have been further assessed regarding their generic knowledge about sustainability. For the purpose of the holistic evaluation of an activity, also video comments and personal interviews of the participants have been used.

Limitations of the study

The overall process of implementation and operation of Living Lab LOW3 at the ETSAV campus, as well as all main educational activities related to it, have been driven and directed by the author. According to a naturalistic (also constructivist) approach to research, results are influenced by the researcher and the context. This is clearly the case in this action research project as the researcher (the author) is one of the actors in the observed activities.

The grade of validity of the inquiries can be considered as high, as all inquiries have been done anonymously in paper format or online. All participants have shown great responsibility during the related educational activities, so honesty in the answers can be taken for granted.

In some of the inquiries one particular participant may have misunderstood the rating system 1 to 5, giving continuously atypical negative ratings, but for reasons of coherence of the overall outcomes, these answers have been taken for valid and have been included as all others.

Study groups

The study groups in this research have been the different participating groups in the Living Lab activities between 2011 and 2015. These groups have been diverse in their composition, different in their backgrounds, their levels of study and disciplines, and additionally they attended different and continuously changing course formats.
This diversity compromises the comparability of results between study groups and limits the interpretation of outcomes to each individual activity in its context.

Main study groups that participated and have been assessed are:

- ETSAV students of architecture (undergraduate students)
- Master Sustainability Students (Master students, different disciplines)
- KIC Master RENE Students (Master students, different disciplines)
- KIC Master SELECT Students (Master students, different disciplines)
- International PhD Students (PhD students, different disciplines)
- TU/e Master Students (Master students, different disciplines)
- HfT Bachelor Students (Bachelor students, different disciplines)

Beyond HE, other study groups such as professionals, school children, and the general public have been analyzed and feedback has been gathered about their experience within the Living Lab LOW3 activity (guided visit, educational activity, open doors day).

Methodology

No pre-test / post-test methodology could be applied at the Living Lab LOW3 courses (official academic courses within ETSAV curricula and the IS.UPC Master Program Sustainability) due to the lack of pre-definition of learning outcomes and course content of each course, as an inherent part of the applied participative living lab approach itself.
Qualitative research methodologies have been applied through participants' questionnaires at the beginning and at the end of both courses, reflecting the opinion of participants about certain aspects of the living lab approach, the specific course activity and the related learning outcomes. Other activities like innovation and co-creation seminars have been assessed through final online questionnaires given to the participants about the specific course, their personal evaluation and satisfaction, the achieved learning outcomes, and their opinion about the living lab concept itself.

Type of applied study methods

A series of different methods and tools have been applied in order to gather feedback of participants on specific Living Lab LOW3 activities.

- Living Lab pre and post-course inquiries (questionnaires with 1-5 rating and possibility for personal comments)
- Sustainability Knowledge questionnaire (existing knowledge level)
- SEEQ questionnaire on student satisfaction (course format improvement)
- Concept maps (holistic understanding of sustainability)

- Documentary videos (documentation of process and outcomes)
- Participants video message (individual course evaluation)
- Personal interviews (individual participants feedback)
- Visitors satisfaction inquiry (individual participants feedback)
- Course diary and field notes of the author allowed continuous documentation of each educational activity within its complex context, as a descriptive and subjective means of evaluation.

For each educational activity, a different combination of study methods and tools has been applied, according to the course format, specific research question and technical possibilities. (Table 23)

Type of Activity (number)	**Type of evaluation**	**Type of participants**	**Number of Participants**
Elective courses (2)	-Living Lab pre-course inquiry -Living Lab post-course inquiry -Sustainability Knowledge questionnaire -Concept maps -SEEQ inquiry -Video documentary -Individual participants video message (course evaluation)	International Master students from different disciplines Master Program Sustainability (IS.UPC), together with undergraduate students (ETSAV)	39
Open Co-creation Seminar (1)	-Living Lab post-course inquiry	Undergraduate students (ETSAV), recent graduates in Architecture, Master students	7
1-day Innovation Seminars (5)	-Living Lab post-course inquiry -Video documentary	International Master students mainly from engineering disciplines	78
3-day Innovation Workshops (2)	-Living Lab post-course inquiry -Video documentary	International PhD students from different disciplines	20
House occupancy experiment (1)	-Personal interviews -Video documentary	Master students from different disciplines	2 (+20)
½-day Educational visits (5)	-Feedback of accompanying teachers -Students comments (visitors book, personal conversations)	High school students	120
Guided visits – house exposition to the public (10)	-Visitors satisfaction inquiry	General public (open doors days, professional visits)	350

Table 7.1 Overview about activities and applied evaluation tools

Application of the study / Impact of outcomes on decisions / actions

Individual results of the study have been used in order to improve the concept of related activities. The Innovation and Co-creation seminars 2015 have benefitted from the evaluation of previous experiences, through the development and implementation of a 3-step co-creation process towards a holistic scenario building activity, which was successfully implemented.

The Living Lab LOW3 course 2012 could benefit from the feedback on the previous course 2011/12 in terms of changes in the use of online tools, the structure of self-organized group work as well as a participatory evaluation of course results.

The overall evaluation of educational activities of Living Lab LOW3 allows for further development of innovative educational formats based on the living lab approach and show their degree of relevance for ESD in the field of architecture.

Statistical treatment

Results are based on 1-5 ratings, with calculation of mean values for a sum of questions regarding a specific area (Place, Methodology, Time frame, etc.), indicating standard deviations of individual results.

Problems encountered

The low number of participants in some of the activities compromised the results of general outcomes and conclusions.

Expected outcomes, results and conclusions

Outcomes of the inquiries and course evaluation are mainly descriptive.

Due to the amount of variables within the design of the inquiry (population, number of participants, discipline, level of studies, course design and activities) no causal relations or results can be described. Co-relational interpretations can be drawn with care about certain outcomes, but the quantity of non-controllable variables and even confusion (see chapter above: limitations of the study) recommends a limitation of qualitative interpretations.

In this sense, outcomes must be understood as a temporal *radiography* of specific educational activities in the context of an action research project, which allows for the evaluation and readjustment of certain parameters, tools and methods in order to develop further an overall approach to teaching and learning.

However, conclusions can be drawn individually, regarding specific activities, and holistically analyzed for the whole 5-year period of educational activities in Living Lab LOW3 at UPC BarcelonaTech and its contribution to ESD in that context.

Structured analysis of each educational activity

In order to document the different educational activities the following general structure has be used:

Course documentation and evaluation

1. Description of activity, objectives, methodology, program and intended learning outcomes
2. Personal evaluation of educational activity
3. Results of structured activity evaluation (questionnaires, inquiries, interviews, etc.)
4. Interpretation of results
5. Achieved learning outcomes

6. Specific Learning outcomes regarding ESD
7. Observations
8. Outlook

Appendices

1. Pictures of the event
2. Outcomes of activity (material produced)
3. Participants questionnaire and results
4. Additional documents

The following 10 educational activates have been analyzed:

Activity 1:	Living Lab LOW3 course 2011/12
Activity 2:	Living Lab LOW3 course 2012
Activity 3:	Open Co-creation Seminar
Activity 4:	PhD Workshop 1
Activity 5:	PhD Workshop 2
Activity 6:	RENE Innovation Seminar 2014
Activity 7:	RENE Innovation Seminar 2015
Activity 8:	SELECT Innovation Seminar 2015
Activity 9:	House Occupancy Experiment
Activity 10:	Guided educational Living Lab visits

This thesis includes in the following chapters the results of 2 specific examples of educational research applied to the following activities:

- Living Lab LOW3 elective course 2011/12 (Activity 1)
- Master RENE Co-creation and Innovation Seminar 2015 (Activity 8)

7.4.3 Results I: Living Lab LOW3 elective course 2011/12

This course has been the **first official academic activity** carried out at the beginning of operation of Living Lab LOW3 at the ETSAV campus at Sant Cugat del Vallès in 2011, with the ambitious objective to **operate, monitor and evaluate the LOW3 prototype** at the Campus Sant Cugat between September 2011 and January 2012.

Learning Methodologies were based on **Project-based Learning (PBL)** with a strong **learning-by-doing** approach, including the following activities:

- **Co-creation activities** based on group work (4-6 students) – planning, installation and operation tasks
- **Open group discussions and debates** on sustainability – creation of individual and collective reflection, knowledge exchange and value discussions
- **Collective brainstorming** and reflection about the course concept itself and **co-design** of the course format and content – participatory teaching and learning approach
- **Use of LOW3 as a living lab infrastructure** with its specific character between formal and informal learning environment – social networking

Working groups have been established for 4 different activities:

- **Installations and energy management** for controlled building operation
- **Monitoring and control systems** for building performance evaluation
- **Virtual Living Lab Platform** as learning, communication and dissemination tool
- **Living Lab experiment design** for the design of the experimental house ocupation

Student inquiries at the beginning and at the end of the course allowed receiving ratings on a 1-5 scale leading to the following results:

Generic Competences
The course seems to have fostered several important generic competences, like **interdisciplinary collaborations and transdisciplinary thinking (rated 4.0)** or important abilities regarding collaboration with others like **teamwork, leadership or decision-making (rated 4.2).** This is a subjective evaluation and cannot quantify the degree of competences at the beginning and at the end of a course, but indicates a very positive overall tendency.

Sustainability knowledge
The students valued their existing knowledge in sustainability as regular (2,8). The course seems to have contributed to new knowledge especially in the field of **general sustainability knowledge (rated 4.2)**, but also in the specific knowledge fields of **bioclimatic architecture (rated 3.8)**, and **energy efficient technologies (rated 3.9).**

The ***Co-learning*** **experience (rated 3.3)** and the **Use of virtual Learning Tools (rated 4.2)** have been additional aspects to be evaluated by students.

Living Lab concept
Students confirm the validity of the Living Lab concept as tool for learning at the campus and value very positively its contribution as **collaborative and participatory learning environment (rated 4.3)**, the **transdisciplinary teaching and research in sustainability (rated 4.2)** and also the **holistic education in sustainability (rated 4.1)** and the function of Living Lab LOW3 as **platform for user co-creation and innovation (rated 4.1)**.

Asked about ***"How do you think could a Living Lab in Architecture like LOW3 contribute to improve your studies? What would be the most useful contributions / functions / services in your opinion?"*** students answered the following:

- Makes possible to see and understand new technologies and concepts under real conditons – prototype evaluation (9 out of 18)
- Fosters **collaboration and participation** in learning on sustainability (9 out of 18)
- Helps to create **critical attitude** to sustainability issues, **new visions and knowledge** (8 out of 18)

The answers reflect the positive opinion of students about Living Lab LOW3 for teaching and learning sustainability and as place for debates, interchange of opinions together with the generation of knowledge and the collaborative environment. Self-organization is mentioned positively, the broad view on sustainability of the course and the role of the teacher as moderator instead of authority, leaving protagonism to students themselves.

For a detailed course description and evaluation see Appendix IV.

7.4.4 Results II: Master SELECT Co-creation and Innovation Seminar 2015

This course has been held within a series of Co-creation and Innovation Seminars for international Master students of different diciplines, titeled *Holistic Sustainability Approach for Innovations.*

Learning Methodologies were based on **Project-based Learning (PBL)** and **co-creation activities** including the following:

- Co-creation activities based on **short presentations, collective brainstorming, SWAT analysis, role-play, story-telling** and similar techniques divided into a three-step process.
- Use of the Living Lab infrastructure as a mixture between formal and informal learning environment, allowing the combination of **creative small-scale co-creation sessions**
- Inspiring and personal dialog within the experimental, research-related environment of an energy self-sufficient solar house
- Mixture of group work, debates, co-creation sessions and **explorative and experimental activities**.

A specific exercise focused on the *"Vision-building and story-telling regarding a more sustainable world in 2050 through a 3-step analytic and creative co-creation process",* developing a specific technology/system innovation for Nearly Zero Energy Buildings (NZEBs).

A 3-step working structure has been applied, consistent in:

- **Mindmaps (Concepts + Analysis)** – Brainstorming and creation of complex mindmaps
- **Tables (Facts + Outlook)** - Technological state of the art analysis and ambiton setting
- **Stories (Visions + Ideas)** - Development and presentation of a multi-scale, holistic vision

The **exploration of the Living Lab LOW3 prototype solar house** introduced students in the concept of a Nearly Zero Energy Building
A **debate session with an invited entrepreneur** and expert in the renewable energy sector has been received very positively, giving a first hand impression about the complexity of converting an idea into a marketable product or service.

The **overall objective** of transmitting to and exercising with engineer students a **holistic, transdisciplinary view on sustainability**, analysing and understanding technology within its environmental, economical and social context, has been achieved satisfactorily from the point of view of the author in its role as organizer of the event.

An **online questionnaire** has been used In order to evaluate the results of the seminar and gather participants' feedback about applied methodologies, achieved learning outcomes and the living lab concept itself.

Interpretation of Results
The seminar has received an exceptional high rating in almost all aspects. It seems that the expectation of students have been met to a very high degree with an **overall rating of 4.19.**

Regarding the PLACE, the **Living Lab itself, as a place to meet and work has been rated 4.38,** which confirms ones more that the architecture of this prototype building serves perfectly as a

space for seminars or similar activities, which draw on creativity, communication and innovation, offering an inspiring conceptual environment, but also a comfortable place, with an appealing design, a useful special concept and equipment for fruitful and inspirational work. The location in the "green" part of the campus, its sunny terrace and the good weather during the seminar might contribute to this overall positive experience.

Regarding the applied METHODOLOGY the **expert contribution has been rated 4.53**, showing a full satisfaction of students with the possibility to speak to an renewable energy entrepreneur who transmits his experience and shares his specific knowledge not only about the energy sector but specifically about how to be successful in new business creation, innovation in product and business models as well as

Regarding the TIME FRAME of the seminar, the **balance between explorative activities, group work, presentations and open discussions has been rated 4.22,** showing that students perceived the structure and content of the seminar program as the right mixture between different working formats and experiences. This contributed to the overall success, as it kept students motivated and dynamic during the whole day.

Regarding the LEARNING EXPERIENCE and asked for the transmission of knowledge through the seminar, the **holistic understanding of sustainability (environment, technology, economy, society) has been rated 4.06**, which shows that the objective of the seminar of a 'holistic approach to sustainability' has been fully achieved. Knowledge transmission in the field of **renewable energy technologies has been rated 3.13**, reflecting the much lower focus on specific technologies, and the background of participants, trained already widely in the field of renewable energy technologies as engineers.

Teamwork and communication (3.97) as well as **Scenario building and Storytelling (4.09)** have been rated very positively in the field of competences, skills and abilities, validating the applied methodologies and tools of the seminar. Story telling methodology is used for creating holistic and complex future scenarios, an ability which pretends to approach participants to a holistic understanding of the interdependence between technology, lifestyle and sustainability.

Asked for the strength of the Living Lab concept, again the **holistic approach to sustainable life style and energy efficiency (4.09)** and the **experience-based and user-centred research environment (1:1 prototype) (4.06)** have been rated highest, showing the appreciation of participants for this type of teaching and learning approach. This gets also reflected in some final comments of participants, asking for more **contact to architecture students** during the seminar, as well as the **extension of the overall duration**, seemingly based on the perception of a certain lack of time for group work and discussions.

Achieved Learning Outcomes

The application of a **3-step working structure** consistent in the elaboration of mind maps (concept + analysis), tables (facts + outlook) and a story (vision + ideas) regarding to a specific technology or concept applied in the LOW3 solar house, allowed the achievement of the following learning outcomes:

The elaboration of mind maps opened up the discussion within the individual working groups **dealing with complexity** related to the concept of sustainability, opened up minds to **system**

thinking and allowed **creative and communicative group work.**
The elaboration of a table, resuming the state of the art of a certain technology or concept and creating an outlook regarding its further development fostered the capacity of **information generation and management,**
Finally the development of a story, which reflects a future scenario (2050) of a technology or concept, allowed to improve the capacity of participants in the field of **vision building, story telling**, and abilities of **creativity** and **communication** through the graphic representation (posters) and presentation (oral communication) in front of an audience (other participants).

Regarding the *intended learning outcomes*, announced in the seminar program, **entrepreneurship skills and research skills** have been trained differently, namely through the discussion with an entrepreneur in the energy sector and some limited technology research, as due to the time restrains of the course, individual projects of participants could not be in the focus.

Specific Learning Outcomes regarding ESD
Regarding knowledge, skills and competences related to ESD the following specific learning outcomes could be mentioned:

- Creativity: Creation of innovative ideas and scenarios
- Cross-disciplinary thinking: Architecture, society, energy, environment, economy
- System thinking: technology impact at all levels, scales, and over time
- Entrepreneurship thinking: idea to product, product to market, business creation

Participants' evaluations through the questionnaire are in line the achieved learning outcomes described above. They mention very positively the **trans-disciplinary approach towards a holistic view on sustainability**, which is the main underlying concept of the course.

Personal Observations
Differences between first and second year Master students can be described with a more receptive attitude of younger students to get involved in some non-orthodox or unknown methodology, which needs **openness and a willingness for creativity experimentation**. This resulted also in a somehow more consistent outcome regarding concept maps, technology analysis and scenario building. Nevertheless these interpretations strongly depend on the individual participants in each activity and their personal commitment to the course.

Outlook
The 1-day seminar for 'Holistic sustainability approach to innovation' has been held 5 times since 2013. It forms part at the date of writing of 2 different Master Programs and the KIC PhD School. Its concept has evolved towards an efficiently organized workshop activity, which generates a valuable although small-scale contribution to a holistic education of engineers with careers in the field of renewable energy systems. Its trans-disciplinary and participatory teaching and learning approach is well appreciated by participants. The seminars will also in the future form part of the core activities of Living Lab LOW3, constantly improving its formats, applied methods and tools.

For a detailed activity description and evaluation see Appendix V.

7.4.5 Interpretation of results

Detailed documentation of methodologies, learning outcomes, and evaluations of two examples of educational Living Labs activities have been presented in Appendices 4 and 5 regarding the following two activities:

Both projects have received very positive ratings by students and gave additional valuable insight into students' perception of **trained competences and skills**, as well as their opinion about the **Living Lab approach**, the **tools and methods** applied, and their overall satisfaction with the **learning experience** offered.

Regarding the usefulness of the Living Lab approach for ESD, in the case of Living Lab LOW3 mainly **qualitative research methodologies** have been applied, collecting evidence though observation, interviews and personal feedback together with participant's surveys and documentation of outcomes, conditioned by the specific context and setting of LOW3 as Living Lab at the ETSAV campus.

For this reason the initial research question "***To which degree have Living Lab LOW3 activities contributed to a holistic SD education at ETSAV / UPC BarcelonaTech"*** can be answered only from a subjective point of view, as no direct comparison could be made with a control group which did not participate in Living Lab LOW3 activities regarding their level of SD competences, nor has been done a pre-/ post-test evaluation, as Living Lab LOW3 is an on-going **action research project**, with constantly changing educational activities.

Nevertheless the presented documentation and evaluation of activities hopefully contribute to a better understanding of how Living Labs can foster ESD in the field of architecture.

The presentation and evaluation of further educational research work would exceed the limits of this thesis and will be part of future publications.

7.5 Application of the 3 step classification and benchmarking tool

In the following section the 3-step classification and benchmarking tools is applied to Living Lab LOW3 and the results are discussed.

7.5.1 Basic differentiation tool (step 1)

Regarding the proposed *basic differentiation* (step 1) of Living Labs, it can be stated that Living Lab LOW3 is a university based Living Lab with a holistic approach to sustainability (Fig, 7.4). It is not industry or market oriented, although technological innovations could be the outcome of some of its activities, like co-creation and innovation seminars for engineering students regarding renewable energies in buildings.

Its general focus is educational and society oriented, with outreach activities to the general public and the support given to initiatives and projects in the field of social innovations.

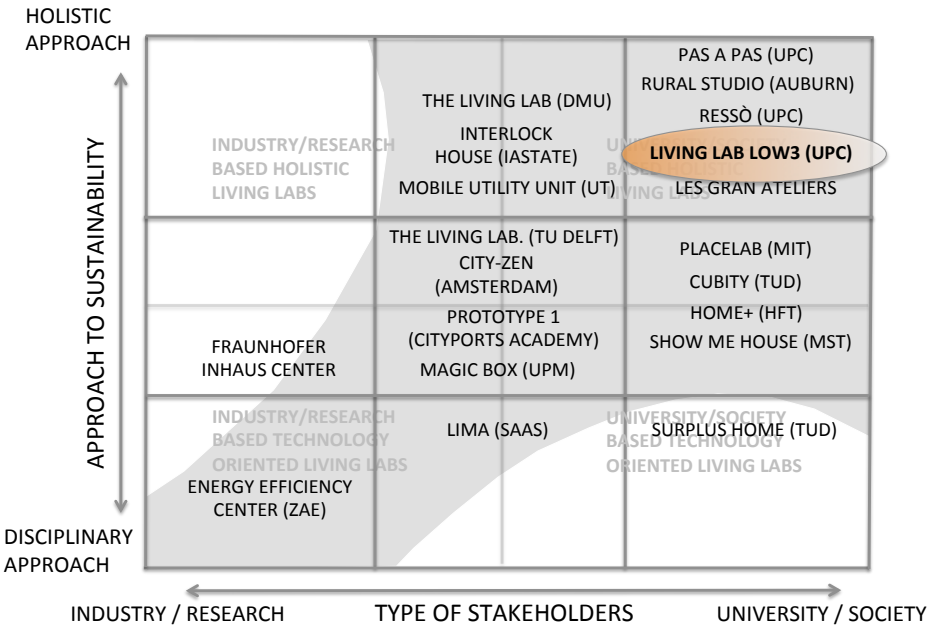


Figure 7.4 Living Lab LOW3 within the *basic differentiation* (step 1) of Living Labs

Living Lab LOW3 has a similar approach as Ressó (case study R17) or PASaPAS (case study R16), projects, which have its origin at the same campus and which are directly linked to each other. Living Lab LOW3 can be seen as more holistic and less industry or research oriented as e.g. Prototype I (case study R19), a project, which has a clear concept for testing market-ready technologies and products.

This basic differentiation may help all kinds of stakeholders to understand a project's characteristics in order to choose the right project for collaboration, or define the desired focus for their own Living Lab project.

7.5.2 Generic classification of Living Lab LOW3 (step 2)

The second, generic classification of Living Lab LOW3 gives information about its basic Living Lab characteristics. The rating has been done by the author as leader of the project, taking into consideration the activities and performance of the last 4 years.

The following rating can be stated Living Lab LOW3:

Living Lab characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **11**						

Table 7.2 Evaluation of Living Lab LOW3 regarding its Living Lab approach (step 2)

Multi-stakeholder approach: medium low
More than 50 companies and entities participated in the original LOW3 project between 2008 and 2010. After the competition, LOW3 could only maintain 3 companies with corresponding funding and collaborations. Currently, companies are not contributing to the regular funding or activities of LOW3 as activities are mainly teaching and applied research-oriented and have a holistic and social focus.

User involvement: high
User-centered research has been carried out through the house occupation experiment "Live-at LOW3", with students as inhabitants evaluating the house concept, comfort and technologies, with a detailed assessment of their lifestyle, personal insights and overall performance. This experiment might be repeated.

Open Innovation: medium low
Open innovation in its classical definition of the externalization of innovation services, did not take place at Living Lab LOW3. Nevertheless Open Innovation can be interpreted as non-profit collaboration between people, institutions or companies in order to share knowledge and innovate for the so-called *common good.* The co-creation and innovation workshop for student initiatives can be considered such an activity, which focused on the free interchange of ideas and collaboration between participants, for the benefit of each one's personal project, applying an open innovation approach.

Real-life environment: medium high
Living Lab LOW3 is a fully functional solar home. Due to its location at a university campus it cannot be considered to be located in a 100% real-life context.

Outcomes: medium high
Outcomes can be valued as positive considering the objectives of the project. A positive mix of teaching and research activities could be linked to the project and many related projects could be supported and networking processes fostered at the campus and beyond.

Organization and structure: medium high
The organizational structure of Living Lab LOW3 can be considered consolidated in the hands of the author and his collaborating team. Nevertheless, no specific committee has been created in order to assess, control or promote the project, and the structure can be considered lean.

7.5.3 Holistic representation of Living Lab LOW3 (step 3)

The holistic representation and benchmarking tool (step3) applied to Living Lab LOW3 gives the following results:

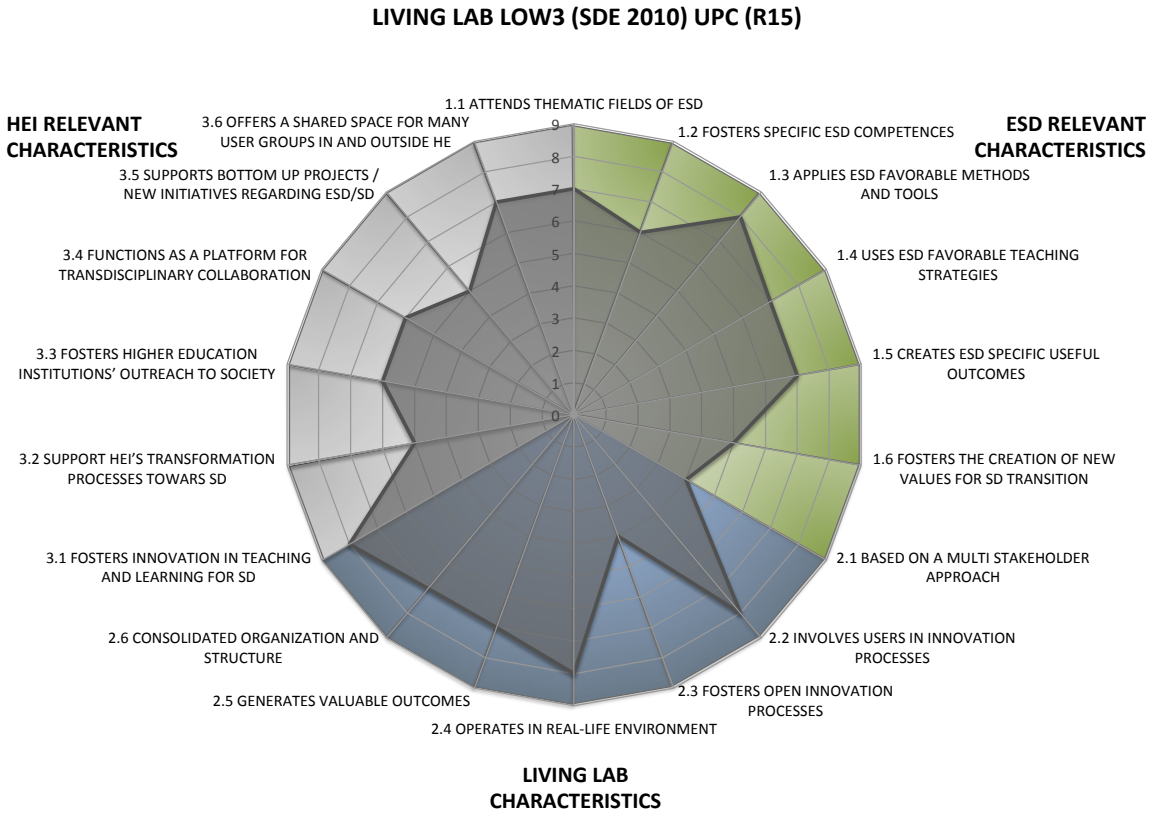


Figure 7.5 Holistic Benchmarking of Living Lab LOW3 (step 3)

The assessment of Living Lab LOW3 has been done by the author and reflects a moderate approach to all important parameters of a Living Lab for ESD in HE. Innovation in Teaching and Learning for SD has been ranked high, whereas the open innovation processes are ranked with caution due to the difficult definition of the concept e.g. referring to the outsourcing of research activities.

It can be stated that many Living Lab parameters have been met by Living Lab LOW3 with others still to develop, e.g. more user-centered, open innovation activities within the Living Lab LOW3 project, and with more intense participation from companies.

Regarding a direct comparison with Magic Box, differences can be stated between both approaches, which are based on the different concepts behind each project, and the different activities which are carried out in each of them.

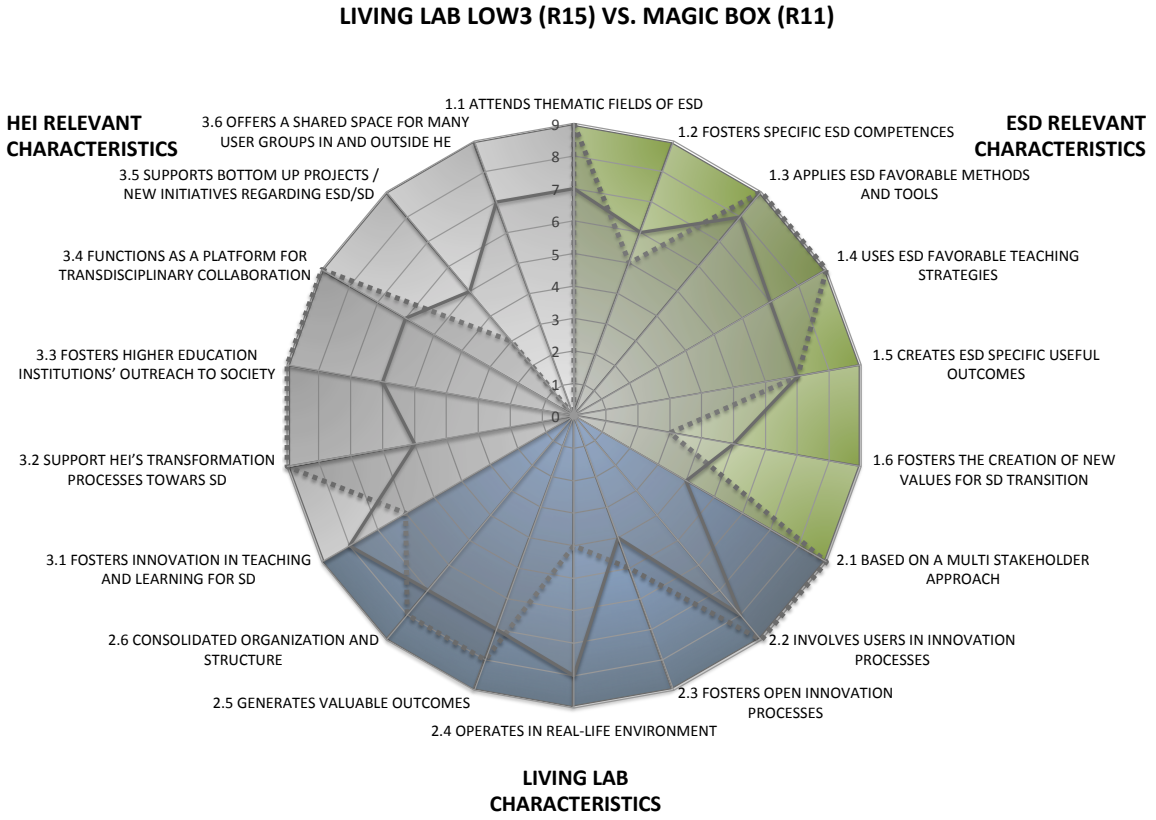


Figure 7.6 Comparison of performance Living Lab LOW3 vs. Magic Box (R11)

The difference between the stakeholders and drivers, a research institute on solar energy and a research unit for solar architecture are a possible explanation for the different profiles of the projects.

7.6 Conclusions

The Living Lab LOW3 project at ETSAV (UPC) has been described in detail regarding the general structure, its educational concept and its activities related to ESD. The developed classification and benchmarking tool has been applied and results have been discussed, showing a fair performance regarding to its Living Lab approach, its ESD activities and its HEI related contributions to SD transition.

Taking into consideration the presented results, and the personal experience of the author with overall responsibility for the project, after 5 years of implementation, field experience and continuous evaluation, the following lessons could be learned from Living Lab LOW3:

- SDE prototype houses like LOW3 are ideal objects to be converted into **Living Labs for sustainable architecture and lifestyle** at universities, but proven methodologies and documented experiences on strategies, tools and outcomes are still rare.
- Students value very positively the **innovative teaching approach** and especially the participatory teaching model of the Living Lab LOW3 courses, but also ask for clear course structures.
- Living Lab LOW3 facilitates the generation of **participatory co-learning activities** that allow collectively generating and distributing new knowledge. A dynamic learning environment with formal and informal activities from workshops and seminars up to co-creation sessions, user-centered research activities and knowledge dissemination for the general public has been created. Its contribution to a holistic SD education at ETSAV (UPC) can be confirmed.
- Important generic and **SD specific competences** could be trained through specific activities at Living Lab LOW3 like its elective courses or its innovation and co-creation seminar.
- The development of **ICT technologies** and societal changes are happening today very fast and universities need to respond to these phenomena (new teaching subjects like NZEBs or smart cities, collaborative learning environments, e-learning, MOOCs, social media, social networks). Living Lab LOW3 shows itself to be an ideal infrastructure for experimenting and integrating these issues into the academic agenda.
- University organizations need to adjust some of their **organizational structures** and administrative mechanisms to handle smoothly activities like SDE, Living Labs or similar projects regarding organization, financing, management and integration in curricula.
- **Indicators** are needed to describe and compare Living Lab projects and their structure, allowing benchmarking of different Living Lab initiatives.
- **Networking** between Living Lab initiatives will be essential in order to learn from different approaches and gain insight in successful mechanisms for their integration in HEIs.
- Living Labs in Architecture like Living Lab LOW3 are powerful tools for improving **architectural education towards sustainability** through a **holistic, experience based, collaborative ESD approach** within non-formal, inspiring learning environments.

8 CONCLUSIONS AND RECOMMENDATIONS

This chapter offers general conclusions of the research done with specific focus on the potential for Architecture Living Labs for ESD in higher education, the corresponding specific framework proposals and the developed 3-step classification and benchmarking tool for Living Labs in architecture. It concludes with an outlook, recommendations and a description of further fields of research.

The initial hypothesis of this work regarding the usefulness of Living Labs in Architecture for ESD led to a series of specific questions, which guided this research:

- ***What are SD specific competences in higher education in general and in the discipline of architecture in particular?***
- ***What are the existing definitions of Architecture Living Labs and which characteristics are most important for their differentiation and benchmarking?***
- ***What are the specific contributions of Architecture Living Labs to ESD in higher education, HEIs SD transition processes, and societal transition towards SD?***

Through this research answers have been formulated, based on an extensive literature review and case study analysis, resulting in framework proposals and the development of a classification and benchmarking tool for Living Labs. Finally a specific case study has been described, resuming the authors' 5-year experience in initiating and running a Living Lab project at a School of Architecture.

In the following results of the individual research steps and deriving conclusions are presented, recommendations are given and future research fields are highlighted.

8.1 SD specific competences in architecture

HEI can have the important role of **agent for societal transformation** regarding sustainable development, although important structural barriers have to be overcome in order to become a stakeholder in **societies' transition towards sustainability**, (Sibbel 2009, O'Byrne et al. 2014).

The critical **re-thinking of the institutional mission of HEIs**, based on a debate that involves all key stakeholders in universities, together with continuous **critical review of knowledge and values,** is identified as necessary for this purpose, as is also **knowledge base and associated values of sustainability** which are unstable and change over time (Wals & Jickling 2002, Wals et al. 2002, Sibbel 2009)

Study programs within the EHEA are defined through corresponding **learning outcomes (LOs)** and **competences**. Competences are usually clustered in three cognitive domains: **knowledge and understanding, skills and abilities**, and **attitudes**. (Segalàs 2009)

The literature review showed that the main **ESD competences** are identified as **critical thinking**, **systems thinking** and **inter- and transdisciplinarity**, with an important role for **values, ethics and attitudes** together with **interpersonal competences**. **Anticipatory, strategic** and **normative competences** complement the existing framework of SD competences (Svanström et al. 2008, Segalàs 2009, Wiek et al. 2011).

In order to foster ESD specific competences, new educational approaches are needed, based on **student-centered, collaborative and praxis-oriented learning** and **creative problem-solving**, applying principals like **active participation, case-study approach, learning by action** through strategies like **project based learning (PBL)** or **problem based learning, backcasting** or **role play** among others **(**Wals & Corcoran 2005, Segalàs 2009).

SD specific competences in architecture do not differ from generally established ESD competences, but are related to discipline specific **knowledge and skills** in order to define specific learning outcomes for architects regarding SD. The literature review shows that focus is given to **sustainable environmental design** with the need to **include global/local strategies for sustainability**, and to address issues of **environmental, social and economic sustainability**, but also to understand historical, social and cultural backgrounds. (EDUCATE 2012)

In order to foster ESD competences in architecture, **pedagogical strategies, methods and tool for ESD in architectural education** should be based on an integrated cognitive framework, discussions and debates, practical and experience-based learning, the interconnection between theoretical lectures and design studios, a research-based, analytic and holistic approach to design and student-centered learning, including **collaborative, problem-based or experiential learning**. (EDUCATE Project Partners 2012)

As HEIs are increasingly incorporating sustainability values and practices in their core activities of **teaching and research,** as well as their **operational structures** (governance, infrastructures, operation, academic community) and their **outreach to society regarding SD**, new strategies, tools and methods are necessary for an overall **transition management of HEIs towards SD**, allowing ESD to be integrated into a comprehensive SD environment of HEIs.

Transition from disciplinary to transdisciplinary, holistic sustainability education in architecture seems to happen best through widening the adopted perspective from project related discourse at local scale, to context related discourse on regional and global scale, shifting the focus from **sustainable architecture education** to **education for sustainable development (ESD).**

8.2 The definition of Architecture Living Labs

Living Labs are defined as **innovation arenas** or **open innovation ecosystems** where different stakeholders can experiment and innovate in real-life environments, involving users in the process (European Commission 2009, Pallot et al. 2010).

4 main characteristics of Living Labs could be identified through literature review:

- **Multi stakeholder approach**: often based on a PPP (Public-Private-Partnership)
- **User involvement**: giving a special role to the user as part of the innovation process
- **Open Innovation**: considering innovation as an open process with multiple stakeholders
- **Real-life environment**: experimenting and capturing user insights in in real-life contexts

The involvement of users as **observed subjects, participants** or even **drivers of innovation processes** through **co-creation** with researchers and other participating stakeholders requires the application of **living lab specific methods and tools**, identified as a weak point in many projects due to a missing common methodological framework. (Mulder & Stappers 2009)

Living Labs can be differentiated through many **characteristics** like the type of stakeholder mix, the type of user involvement, the degree of openness regarding the innovation processes or the degree of real-life environments they are situated in. Other criteria for their differentiation are their functional category as places, organizations or networks, their main drivers, their size, their lifespan and the type of outcomes they produce.

Understanding the **differentiation criteria** of Living Labs, identifying for example. Their type, functional category or main drivers, helps to design or join the right model of Living Lab for a certain kind of innovation project.

Architecture Living Labs are settled at the **intersection of Living Labs** on one side **and Prototype Architecture and Architecture Laboratories** on the other side. They emerge when a **Living Lab approach is implemented within an architectural context**, or when **Prototype Architecture or Architecture Laboratories are opened up to users**, involving them in testing, evaluation and innovation activities within a societal or research context.

Prototype apartments and houses, existing buildings and homes, and with limitations, **laboratories or showrooms, which simulate real-life environments like** office space, or parts of a home can be considered Architecture Living Labs for testing and innovation of **concepts, technologies, products, materials, services or behavior changes models.**

Architecture Living Labs like generic Living Labs, refer to **open innovation environments** (Mulder & Stappers 2009)**, experimental platforms** (Schuurman & De Marez 2009) or **open innovation ecosystems** (Pallot et al. 2010), which allow the **study of users in their everyday habitat** (Schuurman & De Marez 2009) and **co-create and test innovations** collectively with users and stakeholders (Nyström et al. 2012).

The **multidisciplinary approach** to innovation brings together disciplines like **sociology, psychology, biology, engineering disciplines, environmental sciences, physics** as well as **design, architecture** and other **creative disciplines.**

In Architecture Living Labs, users can be **drivers of change,** for example towards **low impact lifestyles** through collaboration in technological development and the adoption or research on behavioral-change models. **Co-creation and innovation** regarding architecture and lifestyle related to the home can be done **for users, with users** or **by users** (Kaulio, cited in Schuurman & De Marez 2009)**.**

Architecture Living Labs are identified as a specific form of **Test and Experimentation Platforms (TEP's),** and many fields of knowledge related to **sustainability**, like energy efficiency, sustainable lifestyle, and in general all **technological or social innovations** related to our living environments, can be researched and developed through this open and co-creative approach to innovation together with users in a real-life context.

Increasing complexity and interactions between physical and virtual elements of our built environment will lead to **fully connected and controlled environments**. Architecture Living Labs can contribute to the corresponding **systemic innovation processes**.

8.3 Classification and benchmarking of Living Labs in Architecture

After a theoretical and phenomenological description of Living Labs in Architecture and ESD related to the discipline of Architecture in HE, a detailed case study analysis allowed the classification of projects and the development of a holistic classification and benchmarking tool in order to assess projects and evaluate their success in combining both approaches.

Case study analysis

25 historical examples of Architecture laboratories and prototype architecture have been described in order to understand the origin of user-centered research in architecture under real-life conditions**,** two basic qualities of what is described today as the Living Lab approach. (Chapter 3.1)

Furthermore **20 selected case studies of recent Living Labs in Architecture** have been analyzed and described in detail regarding their stakeholders, objectives, laboratory type, facilities and tools, users, projects, activities and outcomes in order to get insight in different Living Lab approaches of real operating projects.(Chapter 4.2).

It has been shown that Architecture Living Labs are based on many different concepts, already reflected in the diversity of their descriptions as **applied research center, showcase home, community laboratory, co-housing neighborhood facility, experimental platform, prototype home**, **office and demonstration building or observational research facility**.

Outcomes could be divided into the basic categories of **research and education focused activities, market oriented products and service development,** and **social innovations.**

Regarding **organizational structure and lifespan,** projects could be divided into ones with **limited organizational continuity and lifespan**, and other more continuous projects **based on consolidated organizational structures.**

Evaluation tool

A **3-step classification tool** for Architecture Living Labs related to ESD in HE has been developed and applied in order to analyze and compare projects at different levels.

The **first step** proposes a ***basic differentiation*** regarding two parameters: **Industry/Research versus University/Society** based stakeholders and **Disciplinary versus Holistic approach to sustainability** identifying **four different categories**, namely

- University/Society based technology oriented Living Labs
- University/Society based holistic Living Labs
- Industry/Research based technology oriented Living Labs
- Industry/Research based holistic Living Labs.

The distribution of the 20 case studies over a 2-axis graph showed certain prevalence for disciplinary focused Living Labs being industry/research driven, whereas more holistic Living Lab initiatives seem to be often university/society driven or have a mixed stakeholder group as main driver (chapter 6.3).

The **second step** proposes a ***generic classification*** of Architecture Living Labs identifying 6 basic benchmarking parameters of Living Labs in order to assess them for each individual project. A **scoring system** and a **graphic representation tool** allow visualizing the **individual and global performance** of a project. Differences between higher and lower ranked Living Labs are discussed in order to detail and justify the different scores (chapter 6.4).

The **third step** proposes a ***holistic representation*** of Architecture Living Labs benchmarked in three areas: **ESD related activities** (1), the **Living Lab approach** (2) and contribution to **HEI's transformational processes** towards SD (3). For this **3 benchmark areas** a set of six **basic benchmark parameters** have been defined with **3 sub-indicators** each, resulting in a total of 54 indicators (chapter 6.5.2)

Through a **holistic graphic representation tool** the performance of each parameter can be visualized, showing the **strengths and weaknesses** of individual projects and allowing a detailed **comparison** between projects and **performance monitoring** over time. The tool has been applied to 5 projects and results show its usefulness for the graphic representation and benchmarking of Living Lab projects.

The presented **tools for differentiation, classification and representation** of Architecture Living Labs contribute to a **deeper understanding** of the character and potential of these types of projects, allowing for benchmarking and evaluation, or can be used for planning new initiatives. Living Lab characteristics and ESD related characteristics can be assessed together, for a better analysis and understanding of **Architecture Living Labs for ESD within the transition processes of HEIs towards SD**.

8.4 Architecture Living Labs in HE for teaching and learning sustainability

Framework proposals

In order to understand the different opportunities of Living Labs in HE environments and in order to define **ESD focused Living Labs** within this context, a general **framework for Living Labs in HE** and a corresponding **HE Living Lab Ecosystem** have been described. The general Living Lab approach and corresponding **descriptors** have been interpreted for **Architecture Living Labs in HE environments**, creating the corresponding application framework. (Chapter 5.2)

Communalities between Architecture Living Labs and ESD related competences and strategies have been revised for the **4 main characteristics** of the Living Lab approach: the multi stakeholder approach, the user involvement approach, the open innovation approach and the real-life setting approach, stating that **Living Labs can be valuable concepts for ESD** and even serve as **transformational tools for HEIs' transition towards SD.** (chapter 5.3)

4 common paradigms have been defined as characteristic for ESD and at the same time inherent to Living Labs, namely **Pluridisciplinary Systemic Approach, Participatory Co-creative Action, Open Collaborative Process** and **Real-Life, Context-related Settings**. A **common conceptual framework of ESD and Living Labs** has been proposed, based on these four concepts. (Chapter 5.4)

The **holistic role of Architecture Living Labs for ESD in higher education** has been highlighted for the three main fields of HE transition towards SD, namely **HEIs' Teaching and Research, HEIs' institutional transformation towards SD** and **HEIs' innovation and outreach.** Specifically described fields of activities indicate how Living Labs can serve as a common platform and connecting elements between HEIs and society, fostering **internal and external transition processes** to sustainable development. (Chapter 5.5)

Finally the four basic **Living Lab activities,** namely co-creation, exploration, experimentation and evaluation have been related to **pedagogical strategies and methods for ESD**, demonstrating that Architecture Living Lab activities in HE could serve both purposes: **Living Lab research and innovation activities and education for sustainable development**. As key educational methods, problem based learning and project based learning (PBL) are identified.

Case study Living Lab LOW3

A specific case study, Living Lab LOW3 (UPC), directed by the author during the last 5 years has been documented, and educational research methods allowed assessing some of the results and outcomes regarding student satisfaction, trained competences and skills. The **Living Lab characteristics** of the project and the different **ESD related teaching and learning formats** have been documented and analyzed. Concept, operation and maintenance have been discussed and the benchmarking tools of chapter 6 have been applied in order to assess its performance.

The project shows that a Living Lab in Architecture can offer valuable contributions to ESD in the discipline of architecture, especially through **experiential learning activities** in real-life environments, which allow for personal interchange and development of participants including value discussions, experience based learning and behavioral change experiments, e.g. through a **real living experience** in a sustainable home.

Living Lab LOW3 shows itself to be an informal learning environment that contributes to social interaction of its stakeholders, the creation of network and collaboration opportunities and important outreach to society.

Conclusions

The potential of the **Living Lab approach for teaching and learning on sustainability** has been demonstrated through extensive analysis of case studies. A Living Lab framework in Higher Education has been described, and the documentation of LOW3 as Living Lab at UPC has contributed through insight into a real Living Lab project. Nevertheless there are still many aspects to investigate in order to fully understand the principals of Living Labs and their potential in higher education and some critical aspects regarding their concept within HEIs:

Critical aspects of Living Lab activities:

- Lack of institutional support and clear research/teaching frameworks which allow integrating Living Labs and their dynamics in universities, their existing curricula and operational structures.
- Missing aspects of collaboration between university-company-administration in the field of open innovation through Living Labs.
- Complexity of Living Lab approach due to the number of stakeholders and its pluridisciplinarity and the physical infrastructure related to it.
- Due to the recent appearance of living lab activities in higher education, there is only a limited experience of mid and long-term developments of these kinds of concepts.

8.5 Outlook

Sustainability science in research and **education for sustainable development (ESD)** are still young disciplines and as such in constant flux and evolution. Transdisciplinary thinking and collaboration are fields yet to be developed within our disciplinary-organized universities.

Collaboration, co-creation or synergies among disciplines, people and entities cannot be forced to happen within the diverse academic context of universities. Nevertheless, **places and infrastructures** can be created that facilitate these essential educational processes. This seems to be one of the most important contributions that Architecture Living Labs can make to higher education.

The strong **link of research as well as innovation and outreach activities to education** can improve and enrich all three areas and create special synergies within academic environments, e.g. at schools of architecture as well as a positive relationship to their social-economic context. In this sense, **Architecture Living Labs as infrastructures of universities** allow an efficient linkage of academic research activities to companies interested in innovation, as prototype buildings allow testing of materials, systems and products under real life conditions.
Living Labs for Sustainable Architecture and lifestyle still need to be fully developed. The step from experimental prototype housing to an **active Living Lab community** with efficient user co-creation processes must be one of the main goals within this context.

The generation of **knowledge for transition processes** towards system changes in our society is closely linked to education of all related societal stakeholders in such processes. Future professionals of the building sector such as architects or building engineers have an important role as well as policy makers, building industry or existing agents of social change. They might be **frontrunners in the field of sustainability** through design, innovation, development and implementation of products, processes or services related to sustainable housing and lifestyle.

As **sustainability is an inherently complex matter**, the ecosystem for teaching, learning and research has to reflect this and show this degree of complexity through real-life settings, context related and holistic approaches to innovation. It has been shown that **Living Labs in Architecture** can contribute to this progress of society towards sustainability as **places for systemic innovation approaches**, research in real-life environments, as experience labs and as **ESD platform** in HEIs for all type of internal and external stakeholders.

8.6 Recommendations

Recommendations can be given to various groups inside and outside academia:

Recommendations to directors of Living Lab initiatives

The developed 3-step classification tool is useful for assessing certain characteristics of Living Lab initiatives. It allows detecting strengths and weaknesses in Living Lab concepts, comparing projects amongst each other, and ratings and ranking them according to the proposed scoring system. The tool can be used by the directors of initiatives to benchmark their approach, track improvements over time or set goals at the start of a Living Lab project.

University Managers:

Living Labs in Architecture offer the opportunity to serve as *HE Transition Arenas for SD* e.g. for bottom-up projects initiated by interested students or faculties. Nevertheless resources are needed in order to support these projects beyond voluntarism. As non-formal learning environments Architecture Living Labs in HE may contribute to diverse community outreach projects, social learning processes, and transformational action in the field of sustainability.

University managers, interested in fostering the holistic SD transition process of their institution should identify emerging *transition arenas* (projects, collectives, places), consolidate their organizational structure and dedicate resources for their decentralized operation as community embedded SD agents while offering networking structures among initiatives.

Recommendations to Directors of Schools of Architecture:

Faculty leaders should specifically support ESD activities proposed by teachers and students. Beside SD embedded in curriculum, societal outreach projects may create the necessary transformational learning experience for students and faculties in order to learn about SD through real projects and specific action in the real-life context of universities. Living Labs in Architecture offer this opportunity.

Recommendations to faculties and students:

Faculties and students should not hesitate to adopt the role of *game changers* in their academic communities regarding teaching and learning sustainability in their disciplines as well as ESD in general. Sustainability is linked to the transformation of our current social, economic, environmental and cultural paradigms towards a new systemic approach, and any action-oriented SD related experience contributes to this step by step process, as transformation is closely linked to the personal development of participants, their skills and competences, and also their values and attitudes. Living Labs in Architecture are complex and resource intensive approaches, but the described frameworks, strategies and concepts can also serve for similar initiatives at a smaller scale.

8.7 ESD and Living Labs: personal reflections

Development from Living Labs to "Home Labs"

In the future Living Labs most probably won't be limited to specific infrastructures or places, but will be everywhere. Future homes will be connected homes, having access to and providing data to the community and infrastructures in which they are a part.

Internet of things (IoT), ubiquitous computing, big data, smart grids, are fusing the digital and physical environment for example in homes, and will convert each built environment into a kind of Living Lab, allowing new forms of collaboration and communication between people and things, and between things themselves.

Through context aware sensoring, "things" will be aware of users' activities, preferences, and context[118], in order to optimize and to a certain degree innovate in processes related to communication, energy, comfort, services or any other systemic function of a built environment. Increasing connectedness of our world will shape essentially the future of Living Labs.

ESD and the velocity of change

Our world and our lives are getting increasingly faster. Technological and societal processes accelerate and are continuous and innovation and change happen every day.

A clear example for this increasing velocity is the field of communication: From sending letters, using land lines, to mobile phone use, to our todays smart *what's up generation* – communication happens in an instant with a "bling" and without touching or doing anything else than looking at a screen.

Regarding sustainable development, this influences all areas in our life.

With instantly and ubiquitous available data and information, changing our behavior and lifestyle daily is already a reality, i.e. consuming ecological goods according to the available information about environmental impact or social justice (fair trade), or the use of electricity at low-tariff hours through the shift of activities and their corresponding loads over time.

[118] http://www.computer.org/web/computingnow/archive/september2013

Also participation in democratic processes has become easier and faster: social platforms allow expressing opinion, creating community and supporting initiatives, protests or request for political change within seconds.

Learning to deal with this fast changing world will be essential part of ESD.

So finally, **Living Labs alone won't solve the challenges of our society in transformation**, but might be valuable shared infrastructures, ecosystems or methodologies for teaching and learning about sustainability, as well as research and innovation regarding sustainable development. Both activities will decisively shape our common future.

8.8 Further Research

This thesis has developed a conceptual framework for ESD through Architecture Living Labs in HE. Further research is necessary on the successful initiative of Architecture Living Labs in HE to create more evidence about the viability and the usefulness of Living Labs for ESD, e.g. through a catalogue of good practices, networks of initiatives and theoretical frameworks for their operation.

The developed classification tool is a first step to a systematic benchmarking of Architecture Living Labs and specifically ESD related projects in HE. The proposed tools should be further developed for successful benchmarking and successful implementation of projects.

Further development of the relatively new Living Lab approach is necessary. Methodologies and tools are in constant change, and more practical experiences on a national and an international level should generate new knowledge that helps these evolving initial concepts.

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Abbreviations

Cmap - Conceptual map
CPV - Concentrated Photovoltaic
DS - Desarrollo Sostenible
EHEA - European Higher Education Area EMSU
ENoLL - European Network of Living Labs
ENHSA – European Network of Heads of Schools of Architecture
ESD Education for Sustainable Development
HE - Higher Education
HEI - Higher Education Institutions
ICT - Information and Communication Technology
IoT – Internet of things
PBL - Project Based Learning R&D
PLE - Personal Learning Environment
SD - Sustainable Development
SDE - Solar Decathlon Europe
SWOT - Strengths, Weaknesses, Opportunities, and Threats, TDO
UN - United Nations
UPC - Technical University of Catalonia

Appendices

Appendix I: 25 Historical Living Labs in Architecture (Case studies H01-H25)

Appendix II: 20 Recent Living Labs in Architecture (Case studies R01-R20)

Appendix III: Documentation of Living Lab LOW3 activities 2011-2015

Appendix IV: Educational Research I: Living Lab LOW3 – Elective course 2011/12

Appendix V: Educational Research II: Living Lab LOW3 - Innovation Seminar 2015

Appendix VI: Publications

Appendix I: 25 Historical Living Labs in Architecture

Project data sheets of 25 examples of experimental 'living lab - like' solar houses and laboratories throughout history of the 20th and beginning 21th century
(Case studies H01-H25)

SELECTED PROJECTS:

H01_ **THE GROWING HOUSE**, Martin Wagner, Berlin, Germany, 1932

H02_ **THE HOME OF TOMORROW**, George Fred Keck, Robert Bruce, Tague, USA, 1933

H03_ **MIT SOLAR HOUSE I**, Prof. Hoyt C., U.S. DOE Building Technology, MIT, Boston, MA, USA, 1939

H04_ **HOWARD SLOAN HOUSE**, George Fred Keck, Illinois (USA), 1940

H05_ **SOLAR HEMICYCLE (JACOBS II HOUSE)**, Frank Lloyd Wright, Middleton, WI (USA), 1948

H06_ **MIT SOLAR HOUSE II**, Prof. Hoyt C., Cambridge, MA (USA), 1947

H07_ **DOVER HOUSE**, Eleanor Raymond, Maria Telkes, Dover, MA (USA), 1948

H08_ **MIT SOLAR HOUSE III**, MIT, Cambridge, MA (USA), 1949

H09_ **SOLAR HOUSE AT RICKMANSWORTH**, Ed Curtis, Rickmansworth, UK, 1956

H10_ **LÖF HOUSE**, James Hunter, George Löf, Cherry Hills, CO, USA, 1957

H11_ **MIT SOLAR HOUSE IV**, Prof.Lawrence B. Anderson, Dr Austin Whillier, Lexington, MA, USA,1959

H12_ **SOLAR HOUSES AT ODEILLO**, Félix Trombe, Jaques Michel, Odeillo, France, 1967

H13_ **SOLAR HOUSE AT NEW MEXICO**, Steve Baer, Alburquerque, New Mexico, USA, 1971

H14_ **MIT SOLAR HOUSE V**, MIT Department of Architecture Cambridge, MA, USA, 1978

H15_ **PROTOTIPO SOLAR DE LA PLATA,** IAS-FABA, Elias Rosenfeld, Buenos Aires, Argentina, 1979

H16_ **IEA LOW ENERGY ROW HOUSES**, B. Lundgaard, L. Tranberg, Thermal Insulation Laboratory (DTU), Kolding, Denmark, 1989

H17_ **IEA_ZERO HEATING ENERGY HOUSE**, Institut für Bau-, Umwelt und Solarforschung, Fraunhofer Institut für Bauphysik, Berlin, Germany, 1989

H18_ **IEA ROW HOUSE**, SINTEF, NTNU, Dept. of Building Technology, Norwegian Institute of Technology, Hamar, Norway, 1989

H19_ **PASSIVE HOUSE,** Prof. Bott, Ridder, Westermeyer, Darmstadt, Germany, 1990

H20_ **SOLAR HOUSE FRIBURG**, Fraunhofer Institute for Solar Research (ISE), Friburg, Germany, 1992

H21_ **HELIOTROP SOLAR HOUSE**, Rolf Disch, Friburg, Germany, 1994

H22_ **VAUBAN ECOLOGIC CITY QUARTER**, City of Friburg, Germany, 2000

H23_ **PLUS ENERGY SOLAR HOUSES**, Rolf Disch Friburg, Germany, 2000

H24_ **BEDDINGTON ZERO ENERGY DEVELOPMENT (BEDZED),** Bill Dunster, London, UK, 2002

H25_ **SOLAR DEATHLON COMPETITIONS**, Department of Energy (DOE), Washington, USA, 2002

H01_ THE GROWING HOUSE, Martin Wagner, Berlin, Germany, 1932

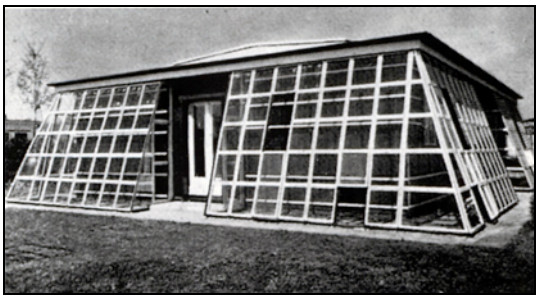


Fig. 1: Growing House south façade

Concept: Prototype and showcase for housing exhibition.

User Involvement: House was not occupied under real conditions of use.

Technology / Energy Features: Direct solar gains, thermal buffer spaces through additional glass envelope, interior zoning, prefabrication.

Monitoring: No information available.

Outcomes: Contribution to passive solar use in buildings.

H02_ THE HOUSE of TOMORROW, George Fred Keck, Chicago, IL, USA, 1933

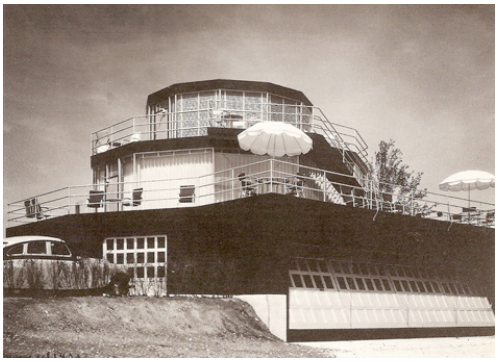


Fig. 2: Glass House of Tomorrow

Concept: Exhibition prototype for the Homes of Tomorrow Exhibition at Chicago World's Fair 1933

User Involvement: Exposition use: opened for visits

Technology / Energy Features: Shop-fabricated steel structure, octagonal floor plan: minimum façade perimeter for energy efficiency, passive solar gains, and solar control devices

Monitoring: Temperature measurements

Outcomes: Keck understood the calorific power of the sun through the glass watching the workers while they construct the prototype. No scientific outcomes.

H03_ MIT SOLAR HOUSE I, Prof. Hoyt C., U.S. DOE's Building Technology, MIT campus, Cambridge, MA, USA, 1939



Fig. 3: MIT Solar House I

Concept: Single story house like structure with sloped roof used as an experimental laboratory at MIT

User Involvement: Occupation as office and laboratory space

Technology / Energy Features: Test of flat plate collectors or "heat traps" integrated in the roof (tilted 30º) with three layers of glass, metal storage tank of 17.000 gallons in the basement for seasonal heat storage

Monitoring: Monitoring over a period of 3 years

Outcomes: Whillier A. (1953) *Solar energy collection and its utilization for house heating.* Thesis Mechanical Engineering, Massachusetts Institute of Technology.

http://hdl.handle.net/1721.1/11922

H04_ HOWARD SLOAN HOUSE, George Fred Keck, Illinois, USA, 1940



Fig. 4: Howard Sloan House, Glenview. South façade

Concept: Single-family house, first passive solar house in history

User Involvement: private home, open to visits

Technology / Energy Features: Direct gain / high projecting shed roofs of dark brown cedar shingles / solar control (porch) / radiant floor heat (radiant-tile panel heating system)

Monitoring: Keck visited "his" houses regularly and received energy consumption data and personal feedback from inhabitants

Outcomes: The prototype was an example of passive solar architecture for many planners and architects. More than 300 people, who visited the Sloan House showed interest in owning or building a solar home.

H05_ SOLAR HEMICYCLE (JACOBS II HOUSE), Frank Lloyd Wright, Middleton, WI, USA, 1948

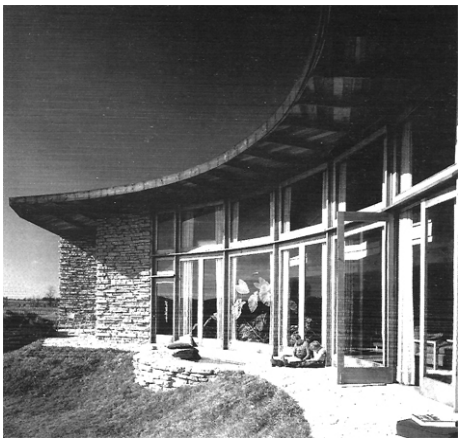


Fig. 5: Jacobs House II, Middleton. South façade

Concept: Single-family house

User Involvement: House under regular use

Technology / Energy Features: Direct gains (semicircle southwest facade), solar control with a cantilever, masonry walls as thermal mass, radiant floor heating system with copper water pipes, sloped earthen berm as natural thermal insulation

Monitoring: Yearly energy bills for heating, personal performance documentation of passive solar heating in winter

Outcomes: The Jacobs hemicycle became one of the first major contributions to the solar house movement, using passive solar design, with a specific solar orientation shaping its geometry and floorplan.

H06_ MIT SOLAR HOUSE II, Prof. Hoyt C., Cambridge, MA, USA, 1947



Fig. 6: MIT Solar House II

Concept: Experimental laboratory (later transformed in MIT solar house III) for solar heat storage through south facades.

User Involvement: Laboratory building without other use.

Technology / Energy Features: Heat collectors on south facing wall with seven different type of collectors to be studied

Monitoring: Laboratory type monitoring

Outcomes: The project generated new concepts for more economical system of solar heat storage, combining in a simple unit the functions of collecting, storing and distributing solar heat. Through parallel testing results could be achieved and compared faster.

H07_ DOVER HOUSE, Eleanor Raymond, Maria Telkes, Dover, MA, USA, 1948

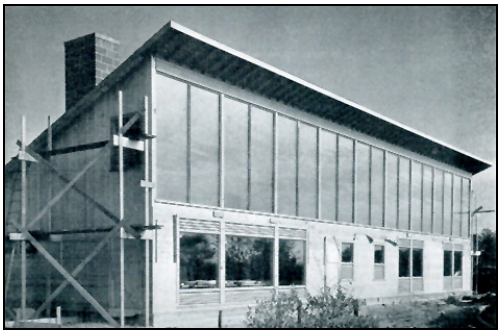


Fig. 7: House for Amelia Peabody at Dover

Concept: Single-family house, with 100% solar space heating, without back-up heater

User Involvement: House was regularly occupied by its owners.

Technology / Energy Features: Solar collectors (black galvanized plate with doubled glazing), heat storage tanks with Glauber's salt as phase change and storage material.

Monitoring: Monitoring of annual performance

Outcomes: During first year, 100% of its space heat from the sun; in subsequent years a decomposition of the Glauber's salt was stated. The solar heating system was replaced through a conventional one on 1953.

H08_ MIT SOLAR HOUSE III, MIT, Cambridge, MA, USA, 1949



Fig. 8: MIT Solar House III

Concept: Experimental laboratory deriving directly from MIT Solar House II, transformed in a single-family house

User Involvement: Inhabited by a student family with one child

Technology / Energy Features: Roof integrated solar heat collectors (tilted 57º), 1200 gallon heat storage tanks with solar heating distributed by ceiling coils, avoiding large ducts **Monitoring:** Laboratory like monitoring

Outcomes: Thermal solar storage allowed to cover approx. 80% of space heating demand through solar heat. The team proposed "a convenient rule of thumb" for collector tilt: the latitude plus 15 degrees.

H09_ SOLAR HOUSE AT RICKMANSWORTH, Ed Curtis, Rickmansworth, UK, 1956

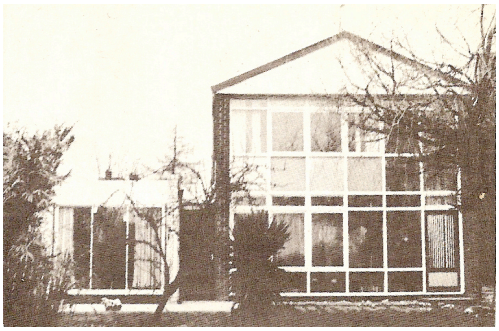


Fig. 9: Rickmansworth House, south façade

Concept: Single-family house

User Involvement: House was regularly occupied by its owners

Technology / Energy Features: Direct solar gain, solar control, simplest every day control devices, insulation: double glazed clear cavity panels, double glazed clear cavity ply glass timber windows, heating system: dual heating-cooling heat pump with single ducting system.

Monitoring: Temperature monitoring

Outcomes: Report: Curtis, Ed (1984) "Solar energy applications in architecture" MARU, Polytechnic of North London

H10_ LÖF HOUSE, James Hunter, George Löf, Cherry Hills, CO, USA, 1957



Fig. 10: Löf House, south-west façade

Concept: Single-family house, prototype for commercial equipment

User Involvement: George Loef residence, private home

Technology / Energy Features: Wood construction, direct solar gain, solar control: eaves and reversible screens, controlled natural ventilation; solar heating system: flat-plate collectors which hot air distribution and 12 tons of gravels for thermal storage, located in vertical bins in the interior.

Monitoring: Monitoring of the whole system for some years.

Outcomes: Discouraging economic balance. Up to 20-25% of energy savings for heating, but high electricity demand for fans.

H11_ MIT SOLAR HOUSE IV, Prof.Lawrence B. Anderson, Dr Austin Whillier, Lexington, MA, USA, 1959



Fig. 11: MIT Solar House IV

Concept: Experimental lab / Single-family house

User Involvement: House regularly occupied by its owners

Technology / Energy Features: Roof flat plate collectors (tilted 60º), 1500 gallon heat storage tanks, heat exchanger (air blown), auxiliary 275 gallon tank heated by oil burner.

Monitoring: Data collection for three heating seasons. No knowledgeable service organization existed to maintain the unique solar heating system so the unit was removed in 1961

Outcomes: Building shape studies for best solar geometry with sloped south façade. Specialized need for maintenance

Bernard,C; et al (1983) *Experimental Comparison of latent and sensible heat thermal walls* on Solar Energy
http://www.sciencedirect.com/science/article/pii/0038092X85900210

H12_ SOLAR HOUSES AT ODEILLO, Félix Trombe, Jaques Michel, Odeillo, France, 1967

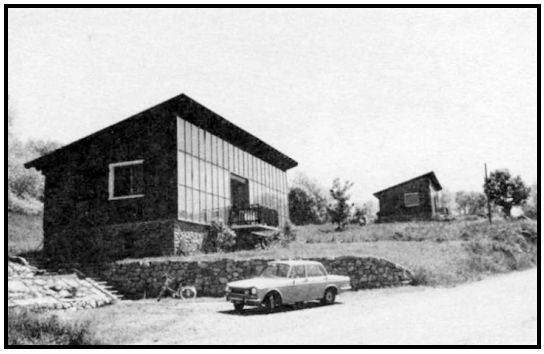


Fig. 12: House at Odeillo, with Trombe-Michel Wall

Concept: Prototype single-family house

User Involvement: House for CNRS workers

Technology / Energy Features: Passive solar heating through Trombe-Michel wall integrated in south façade.

Monitoring: Continuous program of research and development into passive solar systems sponsored by the French Government through CNRS

Outcomes: Givoni,B (1991) *Characteristics, Design implications, and applicability of passive solar heating systems for Buildings*
http://www.sciencedirect.com/science/article/pii/0038092X9190110I

H13_ SOLAR HOUSE AT NEW MEXICO, Steve Baer, Alburquerque, New Mexico, USA, 1971

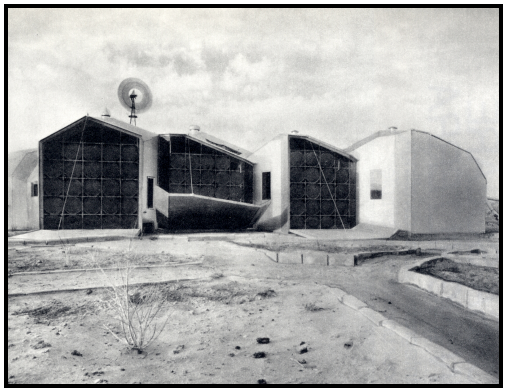


Fig. 13: Solar House at New Mexico

Concept: Single-family home, made by different modules

User Involvement: Baer and his family were the inhabitants

Technology / Energy Features: South wall of 4 modules made by 22 black painted metal drums full of water behind a glass wall: solar passive gain + night insulation through movable insulated panels / natural air ventilation: night cooling of water in summer / forced ventilation (dome effect) / solar collectors

Monitoring: Personal evaluation through the architect/user

Outcomes: Contribution to several techniques of solar thermal storage based on a low-tech self-constructed solutions.

H14_ MIT SOLAR HOUSE V, MIT Department of Architecture Cambridge, MA, USA, 1978



Fig. 14: MIT Solar House V

Concept: Experimental studio –classroom by the MIT Department of Architecture

User Involvement: Regular use of the facilities

Technology / Energy Features: No mechanical equipment; solar gain: narrow venetian blinds between layers of special glass in the south-facing windows that reflected sunlight onto special ceiling tiles for thermal storage using Glauber salt; increased window insulation by transparent plastic material inserted between the panes of glass

Monitoring: Sensors and measurement instruments to record the system's effectiveness

Outcomes: Distinctive architectural design an designed according to the trend to low-tech passive solar houses

H15_ PROTOTIPO SOLAR DE LA PLATA, IAS-FABA, Elias Rosenfeld, Buenos Aires, Argentina, 1979



Fig. 15: Solar Prototype: south façade

Concept: Experimental passive solar house prototype for testing, supported by national Housing Department and Science and Technology Department

User Involvement: Single family house with regular occupation during the assessment. Collection of observations of inhabitants.

Technology / Energy Features: Direct solar gain, greenhouse-drying place (clothes), collector-accumulator water walls, internal insulated enveloping, ventilation and cooling: chimney effect

Monitoring: Test-beds and demonstration building. Two-year campaign of monitoring and testing of all systems

Outcomes: Rosenfeld; et al (1989) *Análisis de un caso: El Prototipo Solar Experimental de la Plata (1979-1985)*

H16_ IEA LOW ENERGY ROW HOUSES, B. Lundgaard, L. Tranberg, Thermal Insulation Laboratory (DTU), Kolding, Denmark, 1989



Fig. 16: Danish Low-Energy Row Houses

Concept: Single-family row houses

User Involvement: Occasional comments were noted, but no specific investigation was conducted: some instructions on how the systems and the building physics work were welcomed; ventilation system caused noise and draught problems; too high indoor temperature as soon as the sun was shining

Technology / Energy Features: super-insulation; super-windows ; solar domestic hotwater; fast-responding heating; heat recovery; energy-efficient appliances and lighting; temperature efficiency of heat recovery

Monitoring: Monitoring and comparison with expected results

Outcomes: Monitored prototype building (European research project, IEA Task 13 "Advanced solar low energy buildings")

H17_ IEA_ZERO HEATING ENERGY HOUSE, Institut für Bau-, Umwelt und Solarforschung, Fraunhofer Institut für Bauphysik, Berlin, Germany, 1989



Fig. 17: German Zero Heating Energy House

Concept: Single-family row house

User Involvement: User aspects were monitored namely: positive evaluation regarding indoor climate and architecture; control system too complex even after two rounds of instructions

Technology / Energy Features: Solar hot water system; seasonal heat storage; super glazing; heat recovery system

Monitoring: Solar energy transmittance of the transparent windows part; total U-value of the windows and south wall

Outcomes: Monitored prototype building (European research project, IEA Task 13 "Advanced solar low energy buildings")

H18_ IEA ROW HOUSE, SINTEF, NTNU, Dept. of Building Technology, Norwegian Institute of Technology, Hamar, Norway,1989



Fig. 18: Norwegian Row House in Hamar

Concept: Single family row house

User Involvement: User aspects were monitored namely: satisfactory daylight and the architecture, audible noise in the living room caused by the heat pump compressor

Technology / Energy Features: High thermal insulation, solar assisted ground heat pump, heat recovery, PV system, sunspace

Monitoring: Monitoring and control of performance through users (Researcher of the project).

Outcomes: Monitored prototype building (European research project, IEA Task 13 "Advanced solar low energy buildings")
http://www.sciencedirect.com/science/article/pii/S0378778804000660

H19_ PASSIVE HOUSE, Prof. Bott, Ridder, Westermeyer, Darmstadt, Germany, 1990



Fig. 19: Passive house in Darmstadt

Concept: Four-unit row house

User Involvement: Regular interviews with the occupants

Technology / Energy Features: *Passivhaus* standard with direct solar gains, thermal insulation, ventilation heat recovery, triple pane glazing, insulated window frames, vacuum tube solar collectors.

Monitoring: Monitoring during several heating periods. Heating Energy Consumption: 19.8 kWh/(m²a), 11.8 kWh/(m²a) and less than 10 kWh/(m²a) (different units monitored).

Outcomes: Feist, Dr.Wolfgang (2006b) *15th Anniversary of the Darmstadt - Kranichstein Passive House. Factor 10 is a reality*

http://www.passivhaustagung.de/Kran/First_Passive_House_Kranichstein_en.htl

H20_ SOLAR HOUSE FRIBURG, Fraunhofer Institute for Solar Research (ISE), Friburg, Germany, 1992



Fig. 20: Solar House Freiburg

Concept: Single-family house

User Involvement: Researcher living inside with family

Technology / Energy Features: Super-insulation, direct solar gains, heat recovery system, home automation, solar control, translucent insulation with thermal storage walls, solar PV and hydrogen storage in combination with fuel cells for electricity supply

Monitoring: Complete monitoring as highly experimental project

Outcomes: Energy autarchy possible, system problems made temporary grid connection necessary. Hydrogen storage system replaced with batteries.

H21_ HELIOTROP SOLAR HOUSE, Rolf Disch, Friburg, Germany, 1994



Fig. 21: Heliotrope solar house Friburg

Concept: Circular, rotating single-family house

User Involvement: Architect lives in the house with family

Technology / Energy Features: Direct solar gain (rotary structure), dual-axis PV tracking system, geothermal heat exchanger, combined heat and power unit (CHP), solar heat and warm water, super-insulation, grey-water recycling system

Monitoring: House is monitored by the architect

Outcomes: Singular prototype building and experiment. A second project was built for a private company.

H22_ VAUBAN ECOLOGIC CITY QUARTER, City of Friburg, Germany, 2000



Fig. 22: Passive Houses Gärnter at Vauban

Concept: Mixed-use eco quarter development

User Involvement: Regular occupied private homes

Technology / Energy Features: Optimized insulation and air-tightness, optimized south orientation for passive solar gains, ventilation heat recovery system, roof overhang and balconies for optimized solar geometry (overheating protection)

Monitoring: No specific information available

Outcomes: Passive house within an ecological city quarter

H23_ PLUS ENERGY SOLAR HOUSES, Rolf Disch Friburg, Germany, 2000



Fig. 23: Plus Energy Solar Houses, Freiburg

Concept: Single-family row houses

User Involvement: Regular occupied private homes

Technology / Energy Features: Vacuum insulated walls, ventilation heat recovery (95%), triple-pane windows, biomass cogeneration unit and roof integrated PV system (mono crystalline silicon), south oriented

Monitoring: Monitoring of individual units

Outcomes: First "Plus-energy" housing development in Germany, producing more energy on a annual base than it consumes.

H24_ BEDDINGTON ZERO ENERGY DEVELOPMENT (BEDZED), Bill Dunster, London, UK, 2002



Fig. 24: BedZED, housing development, London

Concept: Mixed-use eco quarter development

User Involvement: Inhabitants with an engaged behaviour

Technology / Energy Features: Integrated living and working: north facing workspaces with north light; direct solar gains, triple glazed windows, greenhouse sunspace with integrated PV as south façade sun shading device, wind cowl heat exchanger, district heating system: centralized heat and power plant (CHP) with biomass boiler, re-use of grey water and rain water; low embodied energy; local, recycled materials; local *foodstuff*, car pool for residents

Monitoring: extensive monitoring through development company

Outcomes: holistic ecological residential development as "zero emission development" (ZED)

H25_ SOLAR DEATHLON COMPETITION, Department of Energy (DOE), Washington, USA, 2002



Fig. 25: Solar Decathlon Competition 2009, Washington

Concept: Energy self-sufficient solar houses

User Involvement: houses open to public and many of them long-term monitored through university teams

Technology / Energy Features: Energy self-sufficient solar houses with holistically sustainable concepts; energy self-sufficiency on a yearly base, partly with storage devices; ecological building materials; innovative housing concepts e.g. for low cost housing, co-housing or energetic refurbishment of the existing building stock

Monitoring: Complete monitoring of solar houses and all systems

Outcomes: More than 120 prototype buildings constructed in the last years. Many experimental concepts developed for research, teaching and commercial use.

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Appendix II: 20 Recent Living Labs in Architecture

Project data sheets of 20 examples of recent *Living Lab* type laboratories and prototypes including results of generic classification through Living Lab indicators
(Case studies R01- R20)

Selected projects:

R01_ **Energy Efficiency Center**, ZAE Bayern, Würzburg, Germany, 2013

R02_ **Fraunhofer-inHaus Center**, Fraunhofer, Duisburg, Germany, 2009

R03_ **City-zen Test Living Lab,** Amsterdam Nieuw-West, Holland, 2013

R04_ **Living Lab.**, TU Delft (European FP7 Research Project), Holland, 2008

R05_ **Cubity Student Residence *(SDE 2014)***, TU Darmstadt (TUD), Germany, 2014

R06_ **Rural Studio - House for poor people**, Auburn University, Alabama, USA, since 1993

R07_ **Les Grands Ateliers de l'Isle d'Abeau**, HEIs from Rhône-Alpes, Grenoble, France, 2001

R08_ **The Living Lab (IESD)**, De Monfort University (DMU), Leicester, UK, 2011

R09_ **Show Me House *(SD 2007)* - *Solar Village***, Missouri S&T, Rolla, USA, 2007

R10_ **surPLUShome *(SD 2009)* - *Solare Lichtwiese***, TU Darmstadt (TUD), 2010

R11_ **Magic Box *(SD 2005)* - *Campus Montegancedo***, UPM, Madrid, Spain, 2006

R12_ **home + *(SDE 2010)***, HfT Stuttgart, Germany, 2011

R13_ **Mobile Utility Unit *(SD 2002) – CMPBS***, UT Austin, USA, 2002

R14_ **Interlock house *(SD 2009)***, University of Iowa, USA, 2009

R15_ **Living Lab LOW3 *(SDE 2010)***, ETSAV (UPC), Sant Cugat del Vallès (Barcelona), 2011

R16_ **PASaPAS *(SDE 2012),*** ETSAV (UPC), Sant Cugat del Vallès (Barcelona), 2015

R17_ **Ressò *(SDE 2014),*** ETSAV (UPC), Sant Muç (Barcelona), 2015

R18_ **LIMA** [Low Impact Mediterranean Architecture], SaAS, La Salle, Barcelona, Spain, 2009

R19_ **Prototype 1 - *Concept House Village***, CityPorts Academy Rotterdam, Holland, 2012

R20_ **PlaceLab** - ***House_n,*** Massachusetts Institute of Technology (MIT), Boston, USA, 2008

Analysis of the coverage of the following 6 generic living lab characteristics:

- Multi stakeholder approach
- User involvement
- Open Innovation
- Real-life environment
- Outcomes
- Organization and structure

Applied rating system:

Indicators	Fully covered	Widely covered	Partially covered	Not covered
				
Score	3	2	1	0

R01_Energy Efficiency Center ZAE Bayern



Fig. 1: Energy Efficiency Center ZAE Bayern, Würzburg

© Lang/Hugger/Rampp, ZAE Bayern

Start:	2013
Location:	Würzburg, Germany
Main partners / stakeholders:	**Bavarian Centre for Applied Energy Research (ZAE Bayern)** Federal Ministry of Economics and Technology (EnOB-Research) City of Würzburg, ETH Zürich, Landesgewerbeanstalt Bayern (LGA) WVV Würzburg, VR Bank Würzburg
Objectives and goals:	Create a reference building implementing innovative techniques, for research and demonstrational purposes, in order to set new standards. Research and development in the field of energy-optimized buildings, testing scientifically a range of novel developments.
Lab type:	Research and demonstration building
Facilities and tools:	The building includes offices, laboratories and a technical center as well as the corresponding infrastructure for the research activities of ZAE Bayern, allowing the development and practical performance testing of building components integrated in the demonstration building.
Concept:	Demonstration building with evaluation under conditions of real use. The new research building involves innovative, energy efficient materials, components, and systems, all of which are to demonstrate their applicability for both old and new houses. An Information Center located at the main entrance informs visitors about the building concept and the applied innovative technologies.
Users:	Regular users of the building are employees of ZAE Bayern as well as external partners. Feedback from users will provide indications of how the products are performing, pointing out valuable optimization potential to manufacturers and planners.
Projects / activities:	Design Performance Viewer (DPV): modular software, which allows to analyse the energy demand and the emissions of a building in real time Integration of PCM for buffering of temperature peaks in interior spaces Highly insulating window frame system Lightweight membrane roof construction
Outcomes:	Product research and development, patents, publications, services







Fig. 2: Energy Efficiency Center ZAE Bayern, Würzburg. © Lang/Hugger/Rampp, ZAE Bayern

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **14**						

R02_ Fraunhofer-inHaus-Center
Fraunhofer Gesellschaft



Fig. 3: Fraunhofer InHaus at Duisburg, Germany

Start:	2009
Location:	Duisburg, Germany
Main partners / stakeholders:	**Fraunhofer Gesellschaft** Fraunhofer Institute for Building Physics IBP Fraunhofer Institute for Microelectronic Circuits and Systems IMS Fraunhofer Institute for Software and Systems Engineering ISST Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT More than 100 industrial partners
Objectives and goals:	Develop, test and demonstrate new solutions for rooms and buildings. Improve energy efficiency through the use of new materials and automated building services. Optimize the design of office space and hotel rooms. Develop and test innovative construction materials and intelligent building technology. Increase security and assistance for people in care.
Lab type:	InHaus 1: two floor pilot building dedicated to research for the residential sector. InHaus 2: four floors pilot building dedicated to research for the commercial sector.
Facilities and tools:	Health and Care Laboratory, iRoom, Elderly Care 2020 Laboratory, Service Apartment, Single family house, control and monitoring equipment, office space, exposition space.
Concept:	Jointly planned and operated application labs. Cooperation with the inHaus Centre via joint research and development activities with Fraunhofer institutes and inHaus partner companies. inHaus partner categories: system partnerships / component partnerships / application partnerships / sponsorships. Integrated chain of innovation from research through to application and market.
Users:	Users are mainly the participating experts, evaluating the 1:1 prototype installations.
Projects / activities:	Building & planning with support from IT Energy transparency & energy efficiency Logistics and operating processes Interaction between people and technology Multifunctional component building systems Sustainable construction Performance-oriented rooms Security and safety Electronic systems for assisted living
Outcomes:	Patents, services, publications, product developments



Fig. 4: Fraunhofer InHaus at Duisburg, Germany

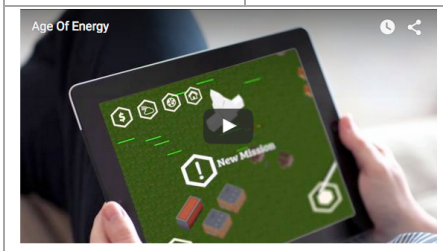
Living Lab characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **16**	↑	↑	↑	↑	↑	↑

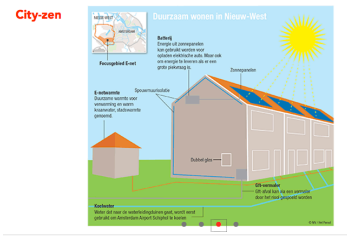
R03_ City-Zen Test Living Lab Amsterdam Nieuw-West	
Start:	2015 (in preparation)
Location:	Amsterdam, Holland
Main partners / stakeholders:	**Amsterdam Smart City (ASC)** as Public-Private-People-Partnership Companies: Liander, Alliander, Daikin, Mastervolt



Fig. 5: City-Zen Test Living Lab Amsterdam

Objectives and goals:	Display and test innovative solutions for buildings in the field of energy efficiency Experiments about how to encourage the user to make "green choices" Scale up innovative energy solutions and open networks
Lab type:	Standard house equipped with innovative technologies as showcase for energy efficient retrofitting
Facilities and tools:	Facilities for showcasing innovative technologies on housing level and for knowledge dissemination about smart energy technologies and concepts on city level
Concept:	Showcase home in the city district Nieuw-West of Amsterdam linked to multiple stakeholders as Public-Private-People Partnership (PPPP). Linked to the European research project City-Zen – New urban energy (EU FP7 project). Part of the Smart Energy Lab Amsterdam.
Users:	Users are neighbours of the city district but also visitors. They participate in behaviour change experiments and knowledge dissemination activities of the Living Lab.
Projects / activities:	Hybrid heat pump technology (combined gas and renewable energy sources) Virtual power plant that allows city residents to trade energy Linked to other City-Zen initiatives like: City-Zen Serious Gaming: Energy saving through awareness raising and behaviour change City-Zen Smart Grid: Intelligent self-healing grids City-Zen Sustainable District Heating: Optimization and innovative solutions for heating grids
Outcomes:	Project not implemented at date if writing.





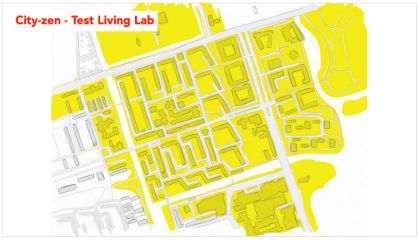


Fig. 6: City-Zen Test Living Lab Amsterdam

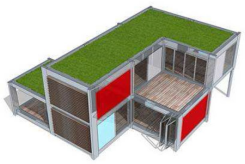
Living Lab characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **8**						

R04_ Living Lab. **TU Delft (European FP7 project)**	
Start:	2008 (not executed)
Location:	European FP7 project, different locations
Main partners / stakeholders:	**Delft University of Technology** ETH Zürich Universidad Politecnica de Madrid (UPM) Wuppertal Institute for Climate, Environment and Energy ACCIONA, BASF, Procter & Gamble



Fig. 7: Design proposal Living Lab.

Objectives and goals:	To research human interaction with, and stimulate the adoption of, sustainable, smart and healthy innovations around the home. To address environmentally critical forms of consumption and to contribute to the realisation of sustainable households in Europe. To understand and model the way physical/technical interventions in the domestic environment change the behaviour of household consumers and its effects on the sustainable performance. To validate the developed behaviour change models, by evaluating their predictive quality for sustainable behavioural change in a realistic setting.
Lab type:	Housing unit as standardized LIVING LAB Research Infrastructure.
Facilities and tools:	Living Lab houses with flexible, modular design. Standardized basic layout and functionalities but flexibility to be adapted to local culture, climate and research interests.
Concept:	Cross-cultural research living labs as part of a research infrastructure of networked living lab houses across Europe. Cross-cultural and cross-climate research conducted in parallel at living labs in different countries. LIVING LAB. provides access to large numbers of users, generating insights into living behaviour with data recorded via user-reporting and non-obtrusive observational techniques. Projects will be developed and managed together with local universities, research institutes and companies at different locations in Europe.
Users:	European research community together with collaborating companies. Temporary residents and users participate in co-creation activities, open innovation sessions and workshops.
Projects / activities:	Activities foreseen to stimulate the mass-deployment of: Energy-efficient techniques and products for the home Domestic products and techniques that use renewable energy sources Water-saving techniques and products for the home
Outcomes:	Project not executed. No specific outcomes beyond documents on concept development.



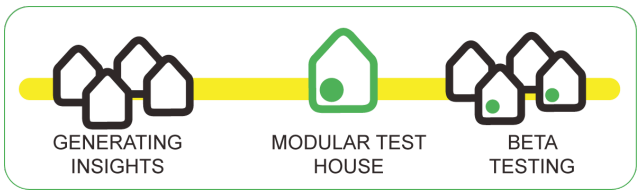




Fig. 8: Design proposal Living Lab

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **11**	↑	↑	↑	↑	↑	↑

R05_ Cubity Student Residence *(SDE 2014)* TU Darmstadt (TUD)	
Start:	2014
Location:	Darmstadt, Germany
Main partners / stakeholders:	**Technische Universität Darmstadt (TUD)** Deutsche Fertighaus Holding AG (DFH) Ministry of Economy Land Hessen Architectura Virtualis GmbH Bollinger + Grohmann GmbH hhp Berlin GmbH INNIUS GmbH Technische Universität Braunschweig



Fig. 9: Cubity Student Residence TU Darmstadt
© Thomas Ott

Objectives and goals:	Research and Experimentation regarding living space for students Research on affordable student housing with Plus-energy standard Evaluation of the prototype building under real conditions of use at the TUD “Lichtwiese” Campus regarding energetic and social aspects
Lab type:	Student residence prototype building (SDE 2014)
Facilities and tools:	Modular student housing for 12 inhabitants, consistent of minimized private space of approx. 7m2 per individual unit and a jointly used hall of 16m x 16m, as shared space with kitchen unit, living area and semi-private access areas to the individual modules. Related infrastructures of TUD “Lichtwiese” Campus for maintenance, monitoring and evaluation.
Concept:	The title of CUBITY unites the main themes: cube, city, and entity. The experimental residential project explores co-housing concepts with shared equipment and a central “market place”. The project attends aspects of flexibility, modularity, transportability, new types of living, renewable energy systems and favourable building costs. After participating in the 2014 Solar Decathlon in Versailles, Cubity is permanently placed at the TU Darmstadt “Lichtwiese” Campus.
Users:	Students living in the residence and possible visitors to the building will participate actively in the evaluation of the project.
Projects / activities:	Evaluation of social and energetic aspects during a 3-year monitoring period at the TUD “Lichtwiese Campus” under real conditions of use as student housing.
Outcomes:	No documented outcomes so fare.






Fig. 10: Cubity Student Residence TU Darmstadt. © Thomas Ott

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **14**	↑	↑	↑	↑	↑	↑

R06_ Rural Studio - House for the poor people Auburn University



Fig. 11: Rural Studio: House for poor people.
© Timothy Hursley

Start:	1993
Location:	Auburn, Alabama,USA
Main partners / stakeholders:	**Auburn University,** School of Architecture, Planning and Landscape Architecture. Donators of the individual projects (companies, individuals)
Objectives and goals:	To offer an undergraduate program to architecture students consistent in an off-campus design-build program for a more hands-on educational experience. To attend an underserved population in West Alabama's Black Belt region, with its specific needs regarding housing and community facilities. To design, build and evaluate the projects together with participating stakeholders like communities, individual tenants or administration.
Lab type:	Individual projects in the local built environment, mainly housing or community buildings.
Facilities and tools:	Auburn University Campus, Open warehouse, materials and construction tools, volunteers.
Concept:	Each project becomes a new and different laboratory of experimentation and development of the overall project. The main work is developed from Auburn University with contribution of companies and private donators. From projects based on recycling, reusing and remaking, project focus shifted since 2001 towards community-oriented work. Main concept of the project is to question what should be built, rather than what can be built, both for the performance and operation of the projects.
Users:	Users are individual citizens and communities in Alabama to whom the projects are addressed and whose needs and opportunities are analysed in order to obtain optimized results.
Projects / activities:	Students work within communities and together with clients or “users” to define solutions, fundraise, design and, ultimately, build projects. Exhibition and events for awareness raising of people.
Outcomes:	To date, Rural Studio has built more than 150 projects and educated more than 600 "Citizen Architects".






Fig. 12: Rural Studio: House for poor people. © Timothy Hursley

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **16**	↑	↑	↑	↑	↑	↑

R07_ Les Grands Ateliers de l'Isle d'Abeau **Higher education institutions from Rhône-Alpes**	
Start:	2001
Location:	France
Main partners / stakeholders:	Funding: Region RhónAlpes Development: **Higher education institutions from Rhône-Alpes** (ENSA Grenoble, ENSA Lyon, ENSA St Etienne, ENSA Clermont-Ferrand, ENSA Montpellier, ENSA Paris Malaquais, ENTPE, INSA Lyon et le CSTB) Strong industry collaboration (Lafarge, CNBD, Serge Ferrari, Vicat, Sant Gobain, etc.)



Fig. 13: Les Grand Ateliers, Grenoble

Objectives and goals:	To offer a platform for experimentation, co-creation and innovation of construction systems, and prototype buildings attending societal challenges like eco construction and sustainable cities. To offer interdisciplinary, practise-oriented training for architecture students and professionals related to the construction sector.
Lab type:	Large-scale construction facility for experimental building activities.
Facilities and tools:	Open warehouse, large scale construction space, materials and construction tools.
Concept:	Experimental laboratory for building construction and construction culture, fostering educational research in innovative, practice oriented teaching and learning. Thematic educational sessions with mixed teams of researchers, practitioners and students. Extended research laboratories involved in a variety of application work, in collaboration with industrial and institutional partners. Different prototype buildings as results with the potential to serve themselves as Living Labs.
Users:	As users can be considered students, professionals, researchers and companies, who project, develop, construct and evaluate different projects at 1:1 scale. Possible user-centred research and evaluation of generated prototype buildings after completion.
Projects / activities:	Educational modules for undergraduate and postgraduate students with up to 50 activities, 15 Schools of Architecture and 6000 students participating each year (2010). Specific focus on environment and eco construction with an increasing relation to real societal problems and challenges. Specific projects: Cité de la construction durable, Solar Decathlon Europe 2012, Solar Decathlon Europe 2010, Concours végétal 2010, Fétes des lumières.
Outcomes:	Publications, competitions entries, exhibitions, videos, prototype buildings, educational activities.






Fig. 14: Les Grand Ateliers, Grenoble

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **16**	↑	↑	↑	↑	↑	↑

R08_The Living Lab (IESD) De Monfort University (DMU)	
Start:	2011
Location:	UK
Main partners / stakeholders:	**De Monfort University in Leicester (DMU)** Institute for Energy and Sustainable Development (IESD) Private companies (Pick Everard)



Fig. 15: The Living Lab Monfort University

Objectives and goals:	Demonstrate how to achieve (and eventually surpass) Government carbon reduction targets in a cost-effective manner. Showcase the latest technological approaches to building and energy management as well as innovative building user engagement. Be a resource for teaching and research into sustainability for buildings, energy and behavioural changes, as well as inspire, teach and live best practice for other public sector buildings in the UK. Create positive energy building concepts for the purpose of research and development (i.e. producing and storing surplus renewable energy at certain times). Demonstrate best practice in innovative building user engagement. Contribute to, and shape future research and policy in the field of buildings, energy and sustainability.
Lab type:	University Building (Queens Building) as Living Lab and showcase.
Facilities and tools:	University Building under real conditions of use, university research facilities, IESD as supporting institute.
Concept:	Development of joint research activities such as Knowledge Transfer Partnerships and research facilities for piloting and exploring novel technologies. Collaborations with Individuals and organisations in order to join forces with DMU and bring their expertise to the project.
Users:	Users of the students, staff and visitors who daily use the building and who might be part of an evaluation process, once the project has started.
Projects / activities:	Project not yet implemented beyond first university-industry contacts.
Outcomes:	No specific outcomes documented.

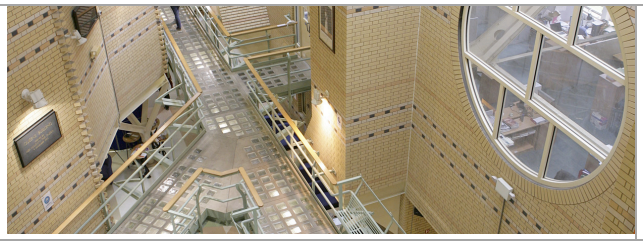
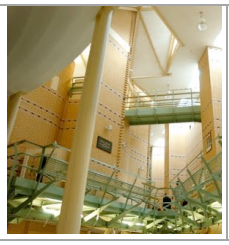





Fig. 16: The Living Lab Monfort University

Living Lab characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **11**						

R09_ Show-Me House *(SD 2009)* - *Solar Village* Missouri S&T	
Start:	2002 / 2010
Location:	Rolla, Missouri, U.S.A.
Main partners / stakeholders:	**Missouri University of Science and Technology (Missouri S&T)** Office of Sustainable Energy and Environmental Engagement- OSE3 Student Design and Experiential Learning Centre Collaborating companies



Fig 17: Show Me House at Solar Village

Objectives and goals:	Show-Me House (SD 2009): Allow users a personal living experience in an energy self-sufficient solar house. Solar Village: Development of research in the fields of Building Science, Electrical Distribution and Material Science with focus on Renewable Energy and Energy Efficient Technologies Promotion of an eco-friendly lifestyle Design, engineer, construct, and market of solar powered homes for Solar Decathlon competition, partnering with numerous corporations for support, displaying a wide range of products
Lab type:	Solar Decathlon competition houses SD 2002, 2005, 2007, 2009 and 2013
Facilities and tools:	Solar houses in a Solar Village setting near the campus under regular use as student housing. Equipment for monitoring of energy performance.
Concept:	Exposition of prototype solar houses under real conditions of use as student housing. Houses serve as teaching objects for students, which can be monitored, visited and explored.
Users:	Undergraduate students participate in activities related to the Solar Village and can even apply for living in one of the 5 solar houses.
Projects / activities:	Micro-grid project, employing alternative and renewable generation, advanced energy storage, and intelligent switching capabilities into a residential facility complex researching technological, legal and societal barriers. Regular public events like the Earth day celebration or guided educational visits.
Outcomes:	Project reports, prototype buildings in use, interactive educational concept for students.






Fig 18: Show Me House at Solar Village

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **13**	↑	↑	↑	↑	↑	↑

R10_ SurPLUShome *(SD 2009)* - *Solare Lichtwiese*
TU Darmstadt



Fig. 19: surPLUShome, TUD
© Thomas Ott

Start:	2005/ 2010
Location:	Darmstadt, Germany
Main partners / stakeholders:	**Technische Universität Darmstadt (TUD)** Interdisciplinary Centre on Technological Research (CIT) Special Program Sustainable TUD Companies and public funding agencies
Objectives and goals:	surPLUShome (SD 2009): To showcase a Plus Energy Solar house and spread related knowledge and concepts to all kind of collectives through guided visits, publications and presentations. To use the prototype for long-term monitoring of systems and components regarding general performance and energy efficiency in collaboration with companies. "Solare Lichtwiese": Construction of a "solar field" by using building-integrated photovoltaic to feed electricity into the German power grid, creating a showcase and fostering a research network for TUD personal. Today: campus space for experimental prototypes of solar architecture for teaching, research and innovation purposes.
Lab type:	Prototype solar house
Facilities and tools:	Resources of the Faculty of Architecture and related institutes for monitoring, research and teaching activities. Other components of "Solare Lichtwiese": Solar House (SD 2007) and Cubity – Plus Energy Student housing (SDE 2014)
Concept:	Exposition of a prototype solar house, which can be monitored, visited and explored. Use as guesthouse for visiting academics planned for the near future.
Users:	Students participate in research and evaluation activities. Visitors and the participating academic community can be considered users. User-centred research and evaluation under real conditions of use in the future, when the house will be used as guesthouse.
Projects / activities:	Educational visits to all kind of public, from students to professionals of the building sector. Monitoring and technical evaluations of systems and products. Temporary use as seminar facility.
Outcomes:	Lectures, knowledge dissemination, publications, product monitoring and validation.

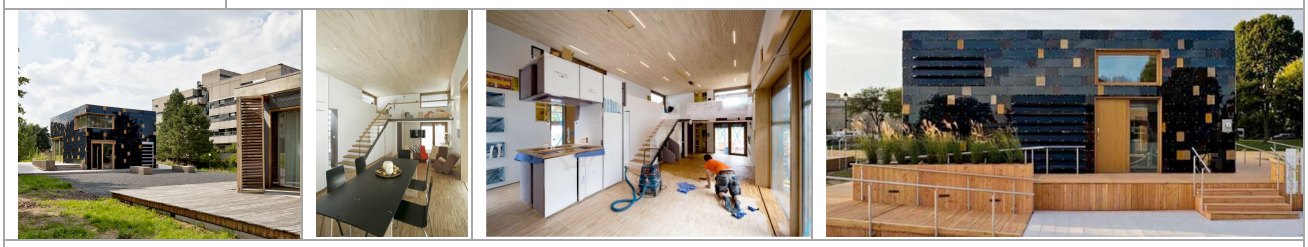


Fig. 20: surPLUShome, TUD. © Thomas Ott

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **11**						

R11_ Magic Box *(SD 2005)* - *Campus Montegancedo*
Universidad Politécnica de Madrid (UPM)



Fig. 21: Magic Box UPM

Start:	2007
Location:	Madrid, Spain
Main partners / stakeholders:	**Universidad Politécnica de Madrid (UPM)** Instituto de Energía Solar (IES) Collaborating companies
Objectives and goals:	To offer a multidisciplinary laboratory for research and training on sustainable buildings, renewable distributed generation and intelligent control. To facilitate the use of a SD prototype as research lab and demonstration site for solar energy in buildings and the possibilities of electric demand management.
Lab type:	Prototype solar houses
Facilities and tools:	Magic Box (SD 2005) SD 2005 prototype solar house, today located near the IES (Solar Energy Institute) at UPM, entity, which supervises and manages all activities related to the project. Campus Montegancedo University research area fostering the creation of an open innovation ecosystem, applying science-driven and open innovation strategies. Experience Labs and Living Labs allow e.g. prototype development and testing including user-centred research. The UPM solar houses Magic Box (SD 2005), Casa Solar (SD 2007) and B&W House (SD 2009) have been mentioned to form part of this project, although no specific information could be found about the current location of Casa Solar and B&W House and Magic Box is located on a different campus of UPM.
Concept:	Magic Box allows the installation, testing and evaluation of technological innovations in the field of energy generation, use, management and storage in buildings.
Users:	Academic community and visitors are users of the prototypes. No user-centred or user-driven research under real conditions of use.
Projects / activities:	Students and young researchers, under the guidance of UPM's professors and researchers can have access to the installation and operational data for their degree practical activities and PhD research objectives.
Outcomes:	A distributed system for the active demand side management of domestic electricity demand: the "GeDELOS-PV" system. 3 PhD thesis.



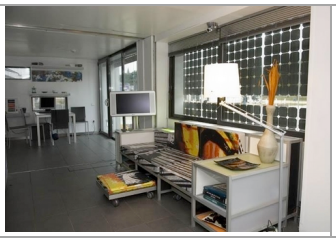



Fig. 22: Magic Box UPM

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **10**	▲	△	▲	▲	▲	▲

R12_ home+ *(SDE 2010)*
HfT Stuttgart



Fig. 23: Home+ prototype HfT Stuttgart
Prof.Jan Cremers. HfT Stuttgart

Start:	2012
Location:	Stuttgart, Germany
Main partners / stakeholders:	**Hochschule für Technik Stuttgart (HFT)** Institute of Applied Research (IAF) Bundesministerium für Wirtschaft und Technologie (BMWi) Private companies Social entities
Objectives and goals:	To convert home+ into a Living Lab for research and teaching of energy efficient architecture. To foster research regarding building climatisation and air-conditioning units with passive and active regenerative technologies. To offer regular visits for general public.
Lab type:	Prototype solar house
Facilities and tools:	Home+ prototype building General university research facilities
Concept:	Technological research project on energy efficient architecture and renewable energies in buildings.
Users:	Academic community, collaborating companies and visitors are principal users of the prototype. No user-centred or user-driven research under real conditions of use.
Projects / activities:	Educational visits for students and the general public. Innovation and testing of PVT (Photovoltaic Thermal Collector) technologies Development and optimization of simulation tools for monitoring operation online. Development of an integrated building information management, control and simulation system in order to optimize energy flow and loads.
Outcomes:	Installation as research infrastructure at HfT, educational activities, research projects, publications.

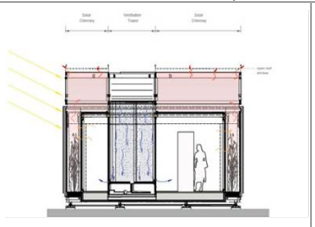





Fig. 24: Home+ prototype HfT Stuttgart. Prof.Jan Cremers. HfT Stuttgart

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **10**	↑	↑	↑	↑	↑	↑

R13_ Mobile Utility Unit *(SD 2002)* - *CMPBS* **UT Austin**	
Start:	2002
Location:	EEUU
Main partners / stakeholders:	**Centre for Maximum Potential Building Systems (CMPBS)** University of Texas Austin (UT Austin)



Fig. 25: CMPBS at Austin, Texas

Objectives and goals:	*Mobile Utility Unit (SD 2002)* The Mobile Utility Unit serves primarily as an office and demonstration building and provides occasional housing for interns and guests of the CMPBS. CMPBS Education, research, and demonstration specialized in life cycle planning and design. Ecological building and master planning design, policy and education initiatives such as green builder programs as well as Sustainable Design and LEED™ Consulting services. Development of analytical tools for understanding and incorporation of sustainability principles.
Lab type:	Prototype solar house
Facilities and tools:	*Mobile Utility Unit (SD 2002)* Former SD 2002 prototype house CMPBS The organizations 18-acre site features experimental structures such as the Advanced Green Builder Demonstration Home as well as a library and a metal and wood fabrication workshop, and lately the 2007 Solar Decathlon House of Texas A&T University.
Concept:	CMPBS—the oldest non-profit organization focused on sustainable design, research, and education in the United States. Its facilities include experimental structures such as the Advanced Green Builder Demonstration and the Department of Energy's demonstration Greenforms building. Prototype houses are understood as a teaching tool and source of inspiration.
Users:	Students and faculties as users of the building, learning, testing and evaluating, and even temporarily living in it.
Projects / activities:	Development of analytical tools that enable better understanding and incorporation of sustainable principles, e.g. the combination of GIS, input/output analyses of the U.S. economy, and life cycle data to address the balance of energy, food, water, air, and materials Advanced Green Builder demonstration site Solar Decathlon prototype solar houses 2002 and 2007
Outcomes:	Publications, protocols, prototypes, teaching and research activities.






Fig. 26: CMPBS at Austin, Texas

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **10**						

R14_ Interlock house *(SD 2009)*
Iowa State University



Fig. 27: Interlock house

Start:	2010
Location:	Rathburn Lake, Iowa, USA
Main partners / stakeholders:	**Iowa State University** Center for Building Energy Research (CBER) The Iowa State Department of Natural Resources National Renewable Research Energy Laboratory (NREL)
Objectives and goals:	To create a solar powered showcase home and interpretative centre at Honey Creek Resort, Iowa. To make the prototype solar house accessible to the general public. To conduct real-time, long-term building performance evaluation of a net-zero energy building through Iowa State students and faculty.
Lab type:	Prototype solar house
Facilities and tools:	Former SD 2009 prototype house – the Interlock House. Additional basement below the house as space for educational activities. Monitoring equipment of building performance evaluation and equipment as interpretative center.
Concept:	Showcase solar home and interpretative centre, which accommodates a range of environmental activities for park visitors. Long-term research and teaching laboratory for energy efficiency in buildings with monitoring activities regarding building performance under local climate conditions.
Users:	Users are office employees, students and visitors who visit the building or participate in activities. User-centred research under real conditions of use. No user-driven research.
Projects / activities:	Iowa NSF EPSCOR Community Laboratory for Energy Utilization Research: Simulation and study of natural ventilation and solar heating effects trough thermal dynamic simulations and building monitoring. Tests on liquid desiccant dehumidification systems, day lighting research, weather data collection. Monitoring of indoor temperature and humidity, electricity consumption as well as electrical and thermal energy production. ASES National Solar Tour – Open house activities.
Outcomes:	Active research laboratory, publications, knowledge dissemination activities.






Fig. 28: Interlock house

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **12**						

R15_ LOW3 Living Lab *(SDE 2010)* ETSAV (UPC)	
Start:	2010
Location:	Sant Cugat del Vallès (Barcelona), Spain
Main partners / stakeholders:	**ETSAV (UPC)** City of Sant Cugat del Vallès, ICAEN Companies: KIC InnoEnergy, REHAU, Valldoreix Greenpower (VGP), Schneider

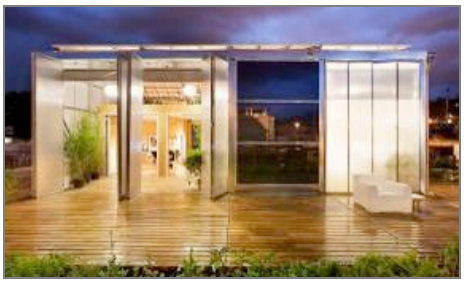


Fig. 29: Living Lab LOW3, ETSAV (UPC)

Objectives and goals:	To convert the LOW3 prototype into a Living Lab as experimental platform for teaching and learning about sustainable architecture, sustainable lifestyle and ESD in general. To foster technological research and education on sustainable architecture, energy efficiency and renewable energies. To design, introduce and evaluate experience-based, participatory learning methodologies, strategies and tools regarding ESD at the campus of a school of architecture.
Lab type:	Prototype solar house
Facilities and tools:	Full functional solar house for real living experiences including data evaluation equipment (OWL energy monitoring, TESTO datalogger, house monitoring system). Space and equipment for explorative and experimental educational activities, seminars and temporary events like open doors days, with exposition space for materials and technologies.
Concept:	Platform for collaborative and participatory learning activities regarding ESD in general with focus on sustainable architecture and lifestyle. Temporary supporting infrastructure for bottom-up initiatives and projects as well as temporary working or exposition space for collaborating companies. Synergies with ETSAV campus facilities: PAuS Experimental Platform, Solar Cube BIPV Laboratory, ETSAV building workshop, e(CO) solar house (SDE 2012) and RESSÒ solar house (SDE 2014).
Users:	Users as drivers for teaching, research and innovation activities: PhD students, postgraduate students, undergraduate students, external visitors (scholars, citizens, professionals) Users as house occupants allow user-centred research, giving feedback on concept, systems and products (Live-at-LOW3 Experiment 2012)
Projects / activities:	Educational Research and Innovation: Living Lab Learning Module KIC InnoEnergy (2011-12) Teaching activities: Elective Undergraduate and Master courses (2011-12), Educational guided visits and explorative activities (2012- on-going), Regular co-creation and innovation seminar activities on Master and PhD level (2013 – on-going) House occupation experiment “Live-at LOW3 (2012) Industry research collaborations (Rehau 2011, VGP 2013) Use as meeting space for project development and networking of student initiatives
Outcomes:	Regular teaching activities, several Master and PhD thesis projects linked, publications.






Fig. 30: Living Lab LOW3, ETSAV (UPC)

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **11**						

R16_ PASaPAS *(SDE 2012)*
UPC



Fig. 31: PASaPAS project setting, Les Planes

Start:	2015
Location:	Spain
Main partners / stakeholders:	**City of Sant Cugat del Vallés (Barcelona)** Neighbourhood Association of Les Planes (Sant Cugat del Vallès) PASaPAS team ETSAV (UPC)
Objectives and goals:	To create a neighbourhood platform for promote an attitude of social change. To promote the interaction between the different players in order to share, participate, believe, imagine and produce a new type of self-managed community service and public space.
Lab type:	Prototype solar house (UPC, SDE 2012) as *Urban Collective Production Laboratory*.
Facilities and tools:	(e)co Solar house rebuilt with a new constellation at the site at Les Planes neighbourhood (Sant Cugat del Vallés) as place for meeting and organizing neighbourhood initiatives. Equipment for meeting and working.
Concept:	Neighbourhood building workshop and platform for social innovation. From prototype to platform: Urban Collective Production Laboratory *Laboratory* as cross experimentation space, involving university research team, neighbours, businesses, and other agents. *Urban* observation point for the environment, able to transform reality based on identified needs. *Production* as paradigm shift and transformation of a consumer society to a productive society. *Collective* space with a proactive and inclusive approach at all stages of reprogramming and use of the platform.
Users:	University research team, neighbours, businesses and other possible agents.
Projects / activities:	Action Research: seeks to establish links with universities and research entities in order to promote the self-regeneration of “Les Planes”, improving the urban metabolism. Co-manufacturing: activities, which provide new knowledge to neighbours. Sociocultural Catalyst: activities designed to promote the collective creation and cultural exchange. Cluster of local and environmental companies: go for local companies in order to enhance their involvement and participation in the needs of the neighbourhood, promoting the local economy.
Outcomes:	First participative neighbourhood projects executed and documented. Supporting infrastructure under construction.






Fig. 32: PASaPAS project setting, Les Planes

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **14**	↑	↑	↑	↑	↑	↑

R17_ RESSÒ *(SDE2014)*

UPC



Fig. 33: Resso prototype at Versailles (SDE 2014)
© André Flaixer

Start:	2015
Location:	Rubí (Barcelona), Spain
Main partners / stakeholders:	**City of Rubí (Barcelona)** Neighbourhood Association of Sant Muç (Rubi) Ressó team ETSAV (UPC)
Objectives and goals:	To create a neighbourhood facility for a low-density neighbourhood near to UPC in order to foster knowledge and neighbourhood action in the field of energy efficiency, renewable energies and sustainable lifestyle, offering a place were social innovation and networking can take place. To encourage applied research initiatives about sustainability, e.g. co-housing or renewable energies in low density urban environments. To spread knowledge and experience of construction, refurbishment and use of low impact buildings under Mediterranean climate. To stimulate the development and application of low impact technologies and new constructive solutions especially for refurbishment of the existing building stock.
Lab type:	Energy self-sufficient prototype solar house (UPC, SDE 2014) as flexible co-housing facility.
Facilities and tools:	Ressó Solar house rebuilt at the site at Sant Muç neighbourhood (Rubí, Barcelona). Bioclimatic building as place for meeting and organizing neighbourhood initiatives and as teaching tool to show bioclimatic systems and solutions, promoting their application in neighbourhood houses. Equipment for meeting and working. Monitoring equipment for indoor comfort control.
Concept:	Neighbourhood building workshop and platform for social innovation
Users:	Neighbours as users of the new infrastructure, learning about energy efficiency. Users as active partners in processes of improving sustainability parameters of the neighbourhood (mobility, energy, social innovation)
Projects / activities:	Evaluation of Building standards of neighbourhood buildings (private homes) Development of refurbishment concepts for housing Coordination of neighbourhood participatory processes and workshops.
Outcomes:	Prototype building under reconstruction, articles and publications, educational activities

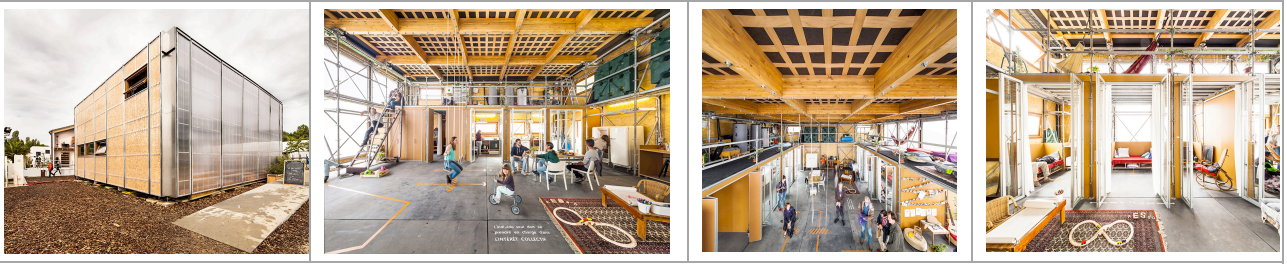


Fig. 34: Resso prototype at Versailles (SDE 2014). © André Flaixer

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **12**	↑	↑	↑	↑	↑	↑

R18_LIMA
[Low Impact Mediterranean Architecture]
SaAS / La Salle (Universitat Ramon Llull)



Fig. 35: LIMA prototype house at URL Campus (Barcelona)

Start:	2009
Location:	Spain
Main partners / stakeholders:	**Sabatè Associats (SaAS)** La Salle (Universitat Ramon Llull) Habitat Saludable, Doppelintegral, Grupo JG, ERF, Societat Organica
Objectives and goals:	To generate a low impact constructive standard that would become in a real alternative to construct houses and other type of buildings, rather in new constructions than in refurbishments. To bring together and coordinate applied research initiatives about the sustainability of Mediterranean urban environments. To design, test and apply tools to evaluate sustainability in construction, refurbishment, and use of buildings in Mediterranean urban environments. To spread the generated knowledge and results about construction, refurbishment and use of low impact buildings, at the Mediterranean and internationality. To stimulate the development and application of low impact technologies and new constructive solutions, for new buildings and refurbishment.
Lab type:	Fully functional low-energy house for real living experience with data evaluation equipment.
Facilities and tools:	Data acquisition systems for comfort evaluation, performance monitoring and system control.
Concept:	Prototype building, which allows obtaining data of interior comfort conditions, energy demand and energy consumption, as well as monitoring data of solar thermal energy generation, solar PV electricity production and water consumption. Firstly situated at the URL Campus in Barcelona as a test bed, the project is actually monitored under real conditions of use as office building at Sant Cugat del Vallès (Barcelona).
Users:	Academic community, companies, office employees.
Projects / activities:	LIMA prototype: Monitoring under real conditions of use, with simulation of different scenarios of occupation and dissemination of results through participation in an international research project on nZEB's.(IEA Task 40) LIMA association: Management of the LIMA prototype activities, evaluation services on building and urban environment sustainability, organization of workshops and technical seminaries as well as collaboration with organizations and institutions.
Outcomes:	Real functional prototype, monitoring results, publications, knowledge dissemination.

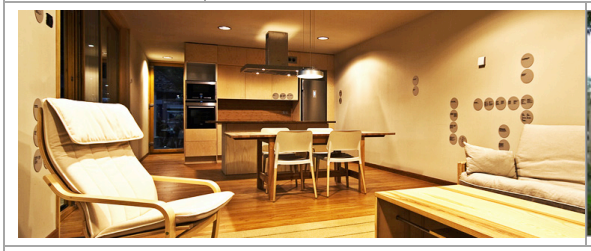






Fig. 36: LIMA prototype house at URL Campus (Barcelona)

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **9**						

R19_ Prototype 1 - *Concept House Village* **CityPorts Academy Rotterdam**	
Start:	2012
Location:	Rotterdam, Holland
Main partners / stakeholders:	**CityPorts Academy Rotterdam (Foundation)** Rotterdam University of Applied Sciences Delft University of Technology Woonbron Housing Cooperation



Fig. 37: Prototype 1 – Concept House Village, Rotterdam

Objectives and goals:	Concept House Village: To facilitate a place where innovative, green, attractive living concepts can be demonstrated and tested for future large-scale rollout. To create a user-oriented testing environment for sustainable building practices, living and sustainable area development. Prototype 1: To showcase the latest technologies regarding sustainable energy, water, sanitation and intelligent homes in order to contribute to a more sustainable built environment. To facilitate monitoring, evaluation and user-centred research under real conditions of use.
Lab type:	Prototype building for user-centred research and testing.
Facilities and tools:	Concept House Village as a whole with its managing and technical infrastructure.
Concept:	Concept House Village (CHV) is a Living Lab where innovative houses, products and systems are tested with and by occupants, together with stakeholders form industry, education and research. The project contributes to speeding up innovations through participation in shared education and research activities and stimulating co-creation and knowledge sharing between stakeholders. Prototype 1 is an energy self-sufficient, factory prefabricated apartment using sustainable materials and technologies. It serves to carry out monitoring, testing and evaluation activities on products and services around the home with the occupant participating in the process.
Users:	Users of the facilities are all consortium members who participate in the specific projects, academic community through linked teaching and research, as well as the general public. User-centred research can be carried out through real occupation and use of the prototypes.
Projects / activities:	Projects are focused on the areas of usability, building and demolition potential and technical functioning of the prototype.
Outcomes:	Real functional prototype, monitoring results, publications, knowledge dissemination.



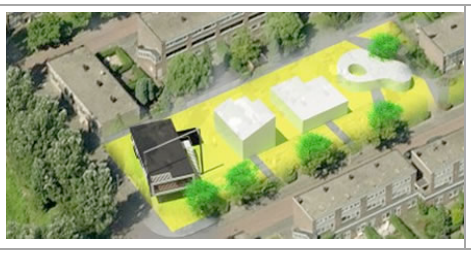




Fig. 38: Prototype 1 – Concept House Village, Rotterdam

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **15**	↑	↑	↑	↑	↑	↑

R20_ PlaceLab - *House_n*

Massachusetts Institute of Technology (MIT)



Fig 39: House_n facilities, MIT

Start:	November 2008
Location:	Boston, Massachusetts, USA
Main partners / stakeholders:	**MIT - House_n Research Group** Department of Architecture, School of Architecture and Planning at the Massachusetts Institute of Technology TIAX (technology processing and commercialization company)
Objectives and goals:	To develop innovative user interface applications that help people easily control their environment, save resources, remain mentally and physically active, and stay healthy through sensors installed in a home. To monitor activity in the environment: researchers study how people react to new devices, systems, and architectural design strategies in the complex context of the home.
Lab type:	One - bedroom condominium with hundreds of sensing components, in a residential condominium in Cambridge, Massachusetts.
Facilities and tools:	PlaceLab facility with hundreds of sensors and observational infrastructure as multi-disciplinary shared scientific tool Portable toolkit of sensors and remote monitoring devices
Concept:	Highly flexible and multi-disciplinary observational research facility for the scientific study of people and their interaction patterns with new technologies and home environments. Open submission process: researchers can submit proposals to use the PlaceLab. High quality proposals are those that can only be accomplished with the unique facilities of the PlaceLab, will fundamentally increase scientific understanding of issues related to life in the home, and consider the long-term implications of the technology, system, or architecture being studied.
Users:	Users are researchers and collaborating stakeholders who use the infrastructure for their studies. User-centred research is carried out through volunteers who agree to live in the home for varying lengths of time.
Projects / activities:	Experimental occupation of the apartment-laboratory has taken place and different studies have been carried out.
Outcomes:	Full functional laboratory, occupation experiments, publications.



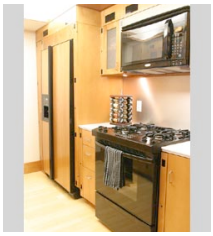



Fig 40: House_n facilities, MIT

Living Lab Characteristics	Multi stakeholder approach	User involvement	Open Innovation	Real –life environment	Outcomes	Organization and structure
Total rating (0-18) **15**	↑	↑	↑	↑	↑	↑

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Appendix III: Living Lab LOW3 _ Activities 2011-2015

Documentation of Living Lab LOW3 activities 2011-2015
See also blog entries: www.livinglab-low3.blogspot.com.es

Main activities since 2011:

- **Living Lab LOW3 course 2011:** re-construction, installation works, analysis, first measurements of the LOW3 prototype solar house at the campus



- **Living Lab LOW3 course 2011/12:** installation works, bioclimatic measurements, holistic evaluation, knowledge dissemination



- **Living Lab course 2012: LIVE AT LOW3 experiment** – activity based on user-centered research: house occupation with 2 students during 2 weeks and holistic evaluation of their lifestyle and impact through the participating student team





- **Related final career projects, Master and PhD thesis work:** Natural ventilation in buildings (2011), The house management system of LOW3 (2012), Personal Learning Environments (2012), Grey water recycling materials (2012) and Living Labs in Architecture (2012)



- **Collaboration in industrial research** project on concentrated solar power systems and energy storage in buildings (2013)



- **ETSAV - 1st co-creation and innovation seminar:** co-creation and innovation seminar giving support to student projects and initiatives related to sustainability (2013)



- **Living Lab Course at HfT Stuttgart:** collaboration with home+ project team of HfT, developing Living Lab concepts for the home+ prototype house. (2013)



- **AUS – Architects for Sustainability Association (COAC) 2013:** Summer meeting at Living Lab LOW3 and visit to ETSAV installations



- **International PhD Seminar on Energy and Participation**: 3-day co-creation and innovation seminar with PhD Students from eastern universities within the International Seminar on Sustainable Energy Technology of IS.UPC. (2013)



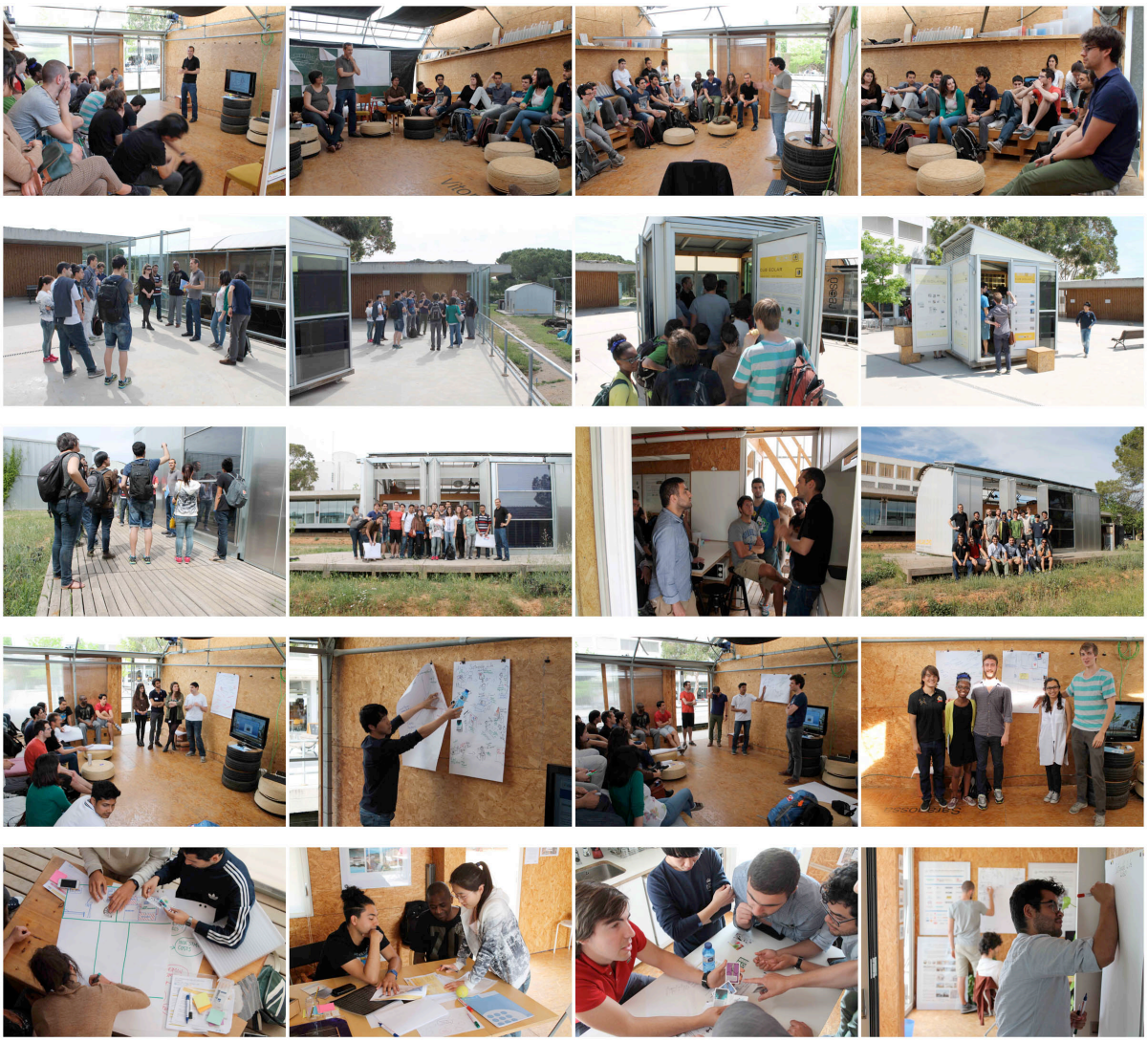
- **Living Lab activity "Zero Home":** Evaluation of the energy consumption profile of LOW3 and exploration of specific user patterns for the design of a energy storage and management concept for up to 100% grid independency (ZERO HOME project)



- **Master RENE (UPC) – Innovation and Co-creation Seminars 2014 and 2015** for international students of the Master “Renewable Energy Systems”, KIC InnoEnergy



- **Master SELECT (UPC) – Innovation and Co-creation Seminars 2015** for international students of the Master "Environomical Pathways for Sustainable Energy Systems", KIC InnoEnergy.



- **Sustainable Summer School 2014:** International PhD Seminar on holistic transition approaches to sustainability, together with Wuppertal Institute, ecosign, UWID



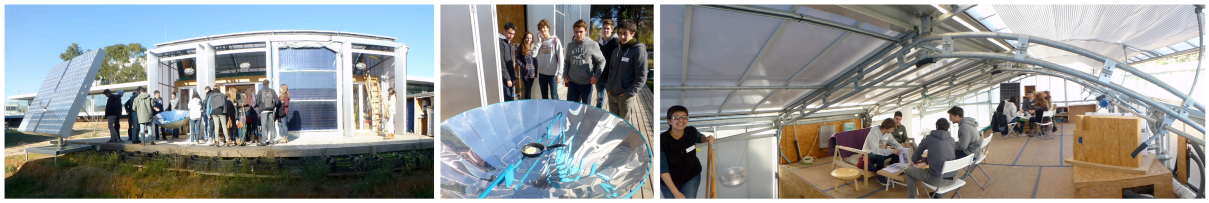
- **Several other activities related to teaching, consulting and dissemination** like educational visits for high school students, professionals or open doors days for the general public, with more than 1200 participants



Educational visits for high school students



Expert's visits organized by professional associations



Academic short visits and experimentation



Field trip of international study programs

Appendix IV: Educational Research I: Living Lab LOW3 – Elective course 2011/12

Documentation of elective course evaluation: Living Lab LOW3 2011/12
ETSAV undergraduate and Master Sustainability IS.UPC programs

Activity:	**LIVING LAB COURSE 2011/12**
Type:	Optional course offered to ETSAV and IS.UPC students
Date:	September 2011 – January 2012
Duration:	1 semester (16 weeks), 4h/week (5 ECTS)
Participants:	ETSAV undergraduate students and Master Program Sustainability IS.UPC
Background:	Architecture, engineering, 5 different nationalities (ERASMUS students)

SHORT DESCRIPTION

Course announcement:

The elective course LIVING LAB LOW3 2011 introduces students in the subject of sustainable architecture through the monitoring and evaluation of a specific project: the energy self-sufficient solar house LOW3 (www.low3.upc.edu), which represented the UPC at the SOLAR DECATHLON EUROPE 2010, based on principles of bioclimatic architecture, sustainable building and the integration of solar technologies.

It is intended to offer a specific vision on the possibilities of sustainable architecture, from bioclimatic mechanisms, solar technologies and their integration in a project, up to the construction with low impact materials, the energy management, monitoring, as well as energetic evaluation and optimization.

The operation, monitoring and evaluation of the prototype at the Campus Sant Cugat between September 2011 and January 2012 is the principal objective of the course and requires a high level of responsibility as well as self-organization and group work.

The course is open to Master students in Sustainability with the aim to link teaching and research activities. Final goal is the establishment of a Living Lab in Architecture at the Sant Cugat campus as innovative learning tool in sustainability.

For more information: cisol@etsav.upc.edu

Objectives

- Get known to the principals of solar architecture, bioclimatic concepts, as well as solar thermal and solar photovoltaic energy.
- Learn about the integration of solar technologies in architecture.
- Monitor and evaluate a real project of a solar house.
- Contribute to the development of a concept for a Living Lab in Architecture.

Course content

Theory 1:

- The Solar Decathlon competition and its solar house prototypes
- The principals of solar architecture (history, technology, research, dimensioning)
- The LOW3 solar house: low energy - low impact - low cost

Theory 2:

- Tools for planning and evaluation: programs, simulation, monitoring
- The integration of solar technologies in architecture: Façades, Energy active building skins
- Perspectives: The present energy scenario – renewable energies – solar energy – sustainability

Activities:

- Re-construction of the LOW3 prototype at the ETSAV campus at Sant Cugat
- Installation and operation of the LOW3 prototype
- Evaluation and optimization of the prototype and its mechanisms
- Development of a concept for a Living Lab in Architecture

Methodologies of Learning

Project-based Learning (PBL) with a strong **learning-by-doing and co-creation approach** as essential methodologies applied in the course activity.

- **Co-creation activities** based on group work (4-6 students) regarding different task necessary for the installation and operation of LOW3 as a living lab at the ETSAV campus.
- **Open group discussions and debates** on sustainability issues, enriched through individual short presentations, short video documentaries regarding sustainable or unsustainable situations in each students personal environment, and holistic analysis of recent political or economical news.
- **Collective brainstorming** and reflection about the course concept itself and **co-design** of the course format and content, developing a first living lab concept and common objectives of the course.
- **Use of LOW3 as a living lab infrastructure** with its specific character between formal and informal learning environment, combining of creative small-scale group work with a personal exchange within the experimental, research-related environment of an energy self-sufficient solar house.

Specific course structure and activities

The course has been structured in a **theoretical and a practical part**.

The first two hours of each session or class have been used for a **holistic approach to sustainability** through group discussions, presentation of individual assignments like descriptive, documentary videos about sustainability issues in each participant's personal environment, individual contributions to a course blog on a virtual platform (Mahara) or reflections on recent sustainability related news. This gave place to participants to take position regarding certain issues like solar energy, nuclear power, lifestyle and related environmental impact, the integration of environmental costs into the price of products, fair trade and western model of consumption among others.

The second part of each session or class has been dedicated to a **"learning by doing approach"** focused on specific issues related to the LOW3 concept like its bioclimatic architecture, the building and energy management, its HVAC system, its solar photovoltaic and solar thermal energy systems, its wastewater treatment. Learning through exploration of the installations, study of manuals and plans and operation of the house has been the applied methodology in order to transmit the related knowledge and open up discussions regarding concepts, technologies and principals of sustainable architecture.

At the same time students co-developed the idea of LOW3 as a living lab for sustainable architecture and lifestyle at the campus, discussing objectives, formats and methodologies which could contribute to a more efficient learning in this fields.

Group work and organization

In order to get known to specific concepts, technologies and systems of a real Nearly Zero Energy Building (NZEB) like LOW3, and prepare LOW3 as a living lab for user centred research and evaluation under real conditions, the following 4 working groups have been established:

- **Installations and energy management:** Installation and operation of main building systems (HVAC, solar energy systems, grey water recycling) and calibration of building and energy control together with external experts
- **Monitoring:** Installation and operation of a control system for monitoring indoor climate, comfort and bioclimatic mechanisms of the house under real use (as place to learn and work)
- **Virtual Living Lab Platform:** Use of virtual tools for working, communication and dissemination of information and results of activities related to LOW3 as a living lab at the ETSAV campus. Activation and exploration of MAHARA (linked to UPC as ATENEA-Lab project) as social learning platform of the course other for future teaching and learning activities.
- **Living Lab experiment design:** Design of a concept for the experimental house occupation and evaluation under real conditions of use with user-centred research about architecture, lifestyle and the overall environmental impact of inhabitants: The Live-at-LOW3 experiment.

Generic and transversal competences according to course announcement**:**
(Predefined competence checklist)

- Critical reasoning: analysis and valuation of different alternatives
- Solution of problems: analysis of optimized solutions for complex projects
- Understand the specifications of a project and design it
- Study norms and standards and apply them to projects
- Written and oral communication: selection and use of the right means
- Search for documental references
- Document real cases
- Elaborate technical reports
- Use of generic software
- Capacity of presenting developed projects
- Use of other languages
- Capacity of doing theoretic/practical work individually
- Capacity of team work: work in an interdisciplinary environment
- Leadership: lead and motivate a group of persons
- Time management: capacity to establish priorities in a project
- Flexibility during project development
- Management of material resources
- Development of artistic sensibility
- Attention to professional ethics and social sensibility
- Attention to environmental aspects

Intended Learning Outcomes

- **Creativity** of students will be fostered through co-creation processes for the design of living lab activities, reflecting about holistic pathways towards a more sustainable society and lifestyle, enhancing the ability to think beyond boundaries and systematically explore and generate new ideas
- **Innovation skills** will be trained enhancing students ability to use knowledge, ideas or technologies to create a new learning platform, designing virtual tools and experiments for holistic, experience-based learning processes
- **Research skills** will be trained through the project-based approach of the course, focused on the exploration of new technological concepts for low energy buildings through a holistic sustainability approach to society and lifestyle
- **Intellectual transforming skills** will be attended through transforming practical experiences at the Living Lab infrastructure into research problems and challenges within an experimental and non-formal learning environment.
- **Leadership skills** will be fostered through the specific group dynamics at the Living Lab courses based on co-creation techniques and joined decision-making processes.
- **Value Judgment** of students will be enhanced through the individual and collective appreciation of ethical, scientific and sustainability challenges which arise during the debate sessions about pathways towards a more sustainable society.

EVALUATION AND OUTCOMES

PERSONAL EVALUATION

The seminar has been fruitful; the foreseen program has been fulfilled, with an active participation of students (total assistants: 18) who showed a good motivation during the different stages of the course. The creative and inspiring working atmosphere through a mixture of group work, debates, co-creation sessions and explorative and experimental activities showed to be an attractive offer to students, used to presentation-like classes and a more passive role in their study programs.
The **introductory presentation session** and 'warm-up' discussions on sustainability created a first common background for the participatory approach of the seminar.

The **exploration of the Living Lab LOW3 prototype solar house** introduced students in the concept of a Nearly Zero Energy Building, its applied technologies, and all related sustainability concepts like low impact building materials, concepts of modularity and co-housing, adapted industrialized construction systems, energy management and bioclimatic architecture, amongst others, with an holistic view on solutions for a more sustainable lifestyle.

The **open debate session** regarding sustainability related matters like sustainable architecture, sustainable lifestyle or transition of society as a whole towards a more sustainable production and consumption model showed to be a good starting point for opening up minds of participants and give them the floor to express their opinion freely,

Discussion of **alternative future scenarios** allowed combining technological visions within a holistic context of society, lifestyle, including environmental aspects and economic considerations.
Due to the open character of the exercise and the specific demand of opening up minds, taking position regarding certain issues, not all participants felt comfortable, as conflicts between opinions arose as part of the process.
The outcomes of these **debate sessions** might seem little specific, the subjects randomly selected, or even a waste of time for some participants, but self- reflection, positioning and reasoning about specific aspects of sustainability contribute to the holistic educational concept of the living lab approach, going beyond the transmission of knowledge, focusing equally on the **development of interpersonal competences**.

During the whole course, the author used to make **personal notes** as a kind of ***course diary*** in order to document and reflect about the process of the course activity, strength and weakness of the concept, conflicts and solutions, as well as the interpersonal experience with the participants and amongst them.

These personal notes led to the following evaluation and analysis of concept, realization and outcome of the Living Lab LOW3 course 2011/12:

Methodology:

- The *active participation approach* of the course has shown to create interesting group dynamics
- The group work helped to structure work and create personal interaction, group dynamics and self-organization

Student dynamics:

- Course format: 4h weekly: problematic, lack of continuity in progress e.g. in construction or installation work
- Student liability: lack of punctuality in assistance, lack of assistance in general (journeys, other courses, deliveries)

Student attitude:

- Students waiting for instructions: 3 weeks for changing this attitude and introducing more participation, a process of change which needs time
- Organization in groups worked quite well, no major problems in collaborations.
- Some students see great opportunities in the course and voluntarily spend more hours in time intensive work like installations. Others show less interest and commitment.

Learning Technology:

- AteneaLab project MAHARA: needed 5 weeks to get established more or less smoothly
- Not as smooth and versatile as Facebook, not as smart for the uses (less intuitive, less visual attractive, less direct information like the "wall" of Facebook)
- Some students are not so familiar with virtual community tools
- Time intensive and technological not mature enough for smooth integration and support of the course. Finally rejected by many participants as not useful.

Technology applied for presentations and classes:

- **PREZI:** interesting presentation tool, visually attractive and fluid with embedded videos through links to YouTube, graphics, images etc. Possibility for co-creation of documents, "co-Prezi", allows making presentations more dynamic
- **Presentation tools:** Presentation of ppt, videos etc. at the Living Lab: Typical problems with the format of documents, lack of memory, incompatibilities and loss of valuable time. Videos developed by students very successful tool for reflection about certain sustainability issues like transportation of goods, energy efficiency etc.
- **C-MAP tool:** only presented and applied at the final evaluation/feedback of the course. An interesting tool to be applied within the next course right from the beginning, in order to show possible improvements through the course in the capacity of participants of a holistic and systemic vision of sustainability.

Documentation of the course:

- **Audiovisual:** Videos were taken of almost every class for posterior analysis of course dynamics,
- **Pictures:** Through the photographic documentation of all activities of the course, a visual description of the activities is possible, transmitting the practical course activities like construction or bioclimatic assessment
- **Reports by students:** The final outcome of all working groups within the Living Lab activities got documented in a final report of the realized works by students.
- **Mahara:** With the virtual semi-formal social network tool Mahara, students discussed on important issues of sustainability in general as well as issues related to their specific works on the LOW3 solar house. Forums of discussions, blogs, and documents like videos form part of this virtual environment with allows to maintain all this information, share it with more participants and
- **Living Lab LOW3 Blog**
- **Facebook group Living Lab LOW3**
- **Twitter account**

PRE / POST-ACTIVITY QUESTIONNAIRE TO PARTICIPANTS

In order to evaluate the results of the seminar and gather participants' feedback about applied methodologies, achieved learning outcomes and the living lab concept itself.
2 questionnaires have been designed. The first questionnaire, handed out at the beginning of the course, asked for a self-evaluation of certain knowledge and competences, learning experience and the interpretation of the concept of living lab.

The **background of the participants,** with an average age of 22 years, was the following:

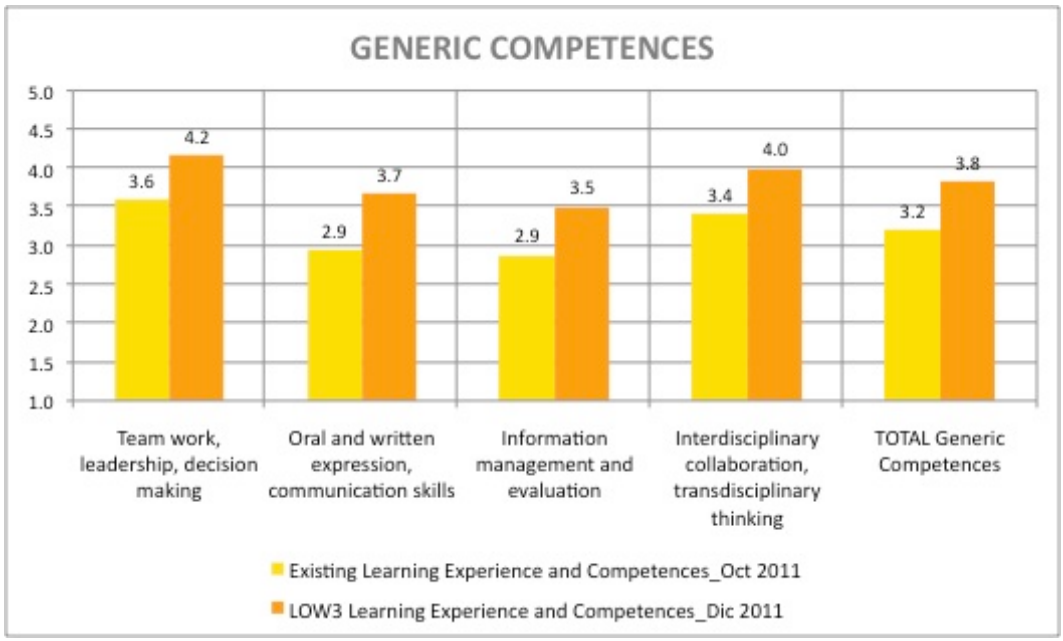
- Architecture students (ETSAV): 16
- Master Program Students (IS.UPC): 2

14 out of 17 students answered the initial questionnaire, which corresponds to an **answer rate of 82,4%** of students giving their initial opinion.
18 out of 18 students answered the final questionnaire, which corresponds to an **answer rate of 100%** of students giving their specific feedback about the activity.

Results of the pre/post-activity questionnaires

Generic Competences
Which generic competences do students think that they already possess, and which ones have been fostered through the Living Lab LOW3 course?

Initial question: "Please valuate your present generic competences"
Final question: "Which kind of generic competences have been attended in the course?"

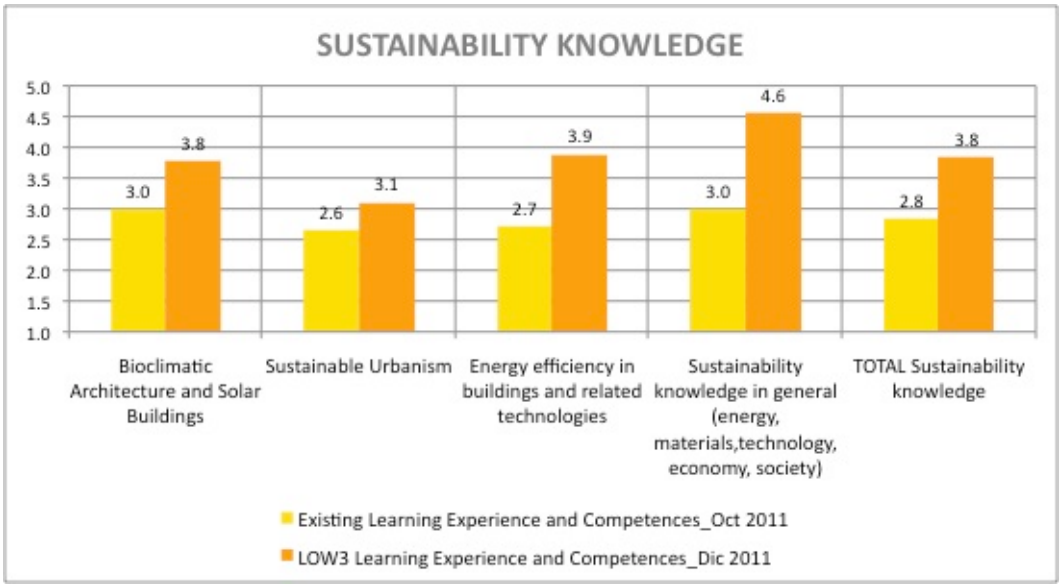


The course seems to have fostered several important generic competences, like interdisciplinary collaborations and transdisciplinary thinking or important abilities regarding collaboration with others like teamwork, leadership or decision-making. This is a subjective evaluation and cannot quantify the degree of competences at the beginning and at the end of a course, but indicates a very positive overall tendency.

Sustainability knowledge

How do students value their knowledge in the field of sustainability at the beginning of the course and how to they value their learning outcomes after the course activity?

Initial question: “Please valuate your present specific knowledge in the following fields”
Final question: “Which kind of specific knowledge has been transmitted in the course?”

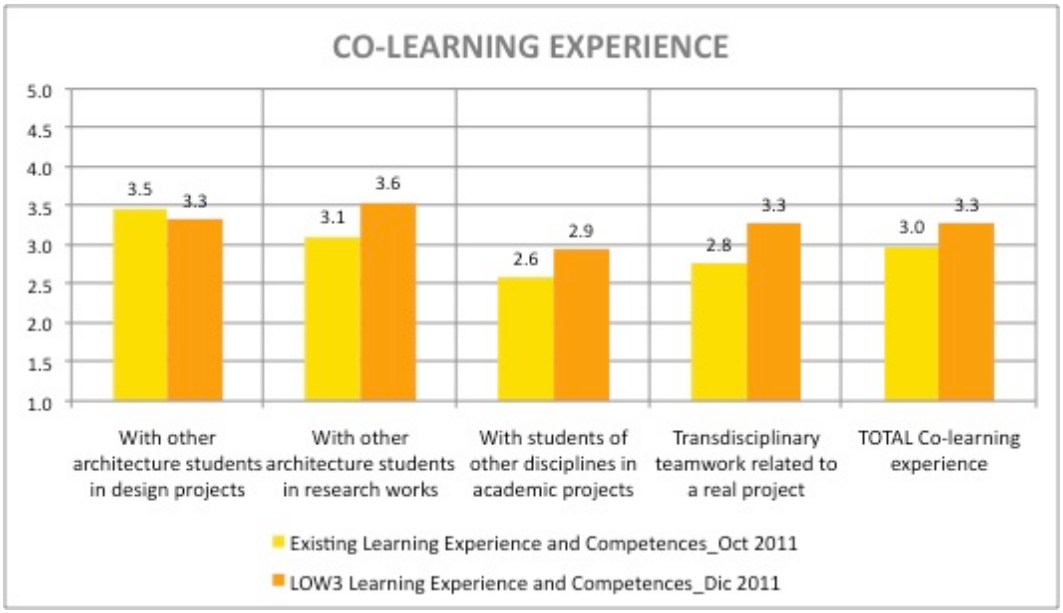


The students value their knowledge in sustainability as regular (2,8). The course seems to have contributed to new knowledge especially in the field of general sustainability knowledge, but also in the specific knowledge fields of bioclimatic architecture, and efficient technologies.

***Co-learning* experience**

Which potential see students in the participative concept of Living Lab LOW3 regarding interdisciplinary collaborations and group work?

Initial question: What is your existing experience in co-learning within university?
Final question: Which kind of co-learning experience did you experience in the course?

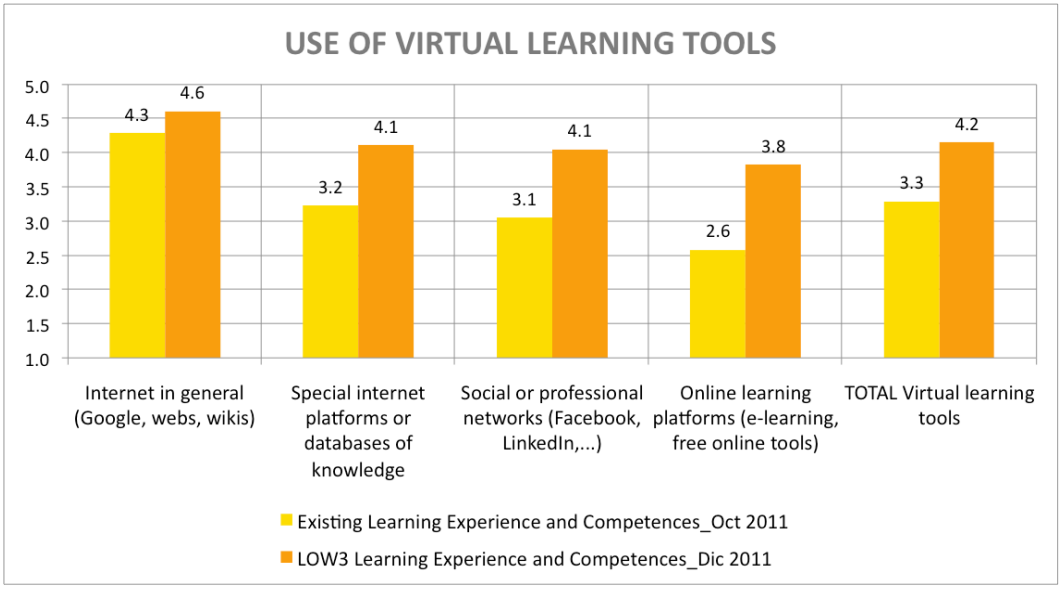


The evaluation of the course is rated a little bit higher than the previous experience of students, nevertheless new pluridisciplinary group dynamics and collaborative teaching and learning activities will have to be improved at Living Lab LOW3.

Use of virtual Learning Tools

Essential part of the course has been the introduction of students to the virtual Learning Platform ATENEA LAB – MAHARA, fore learning and communication and virtual interaction within the course, on individual as well as group level and of course the "moderator" (teacher) of the activities.

Initial question: Which virtual tools for information / learning / communication do you use normally?
Final question: What kind of virtual tools for information/learning/communication did you use in the course?

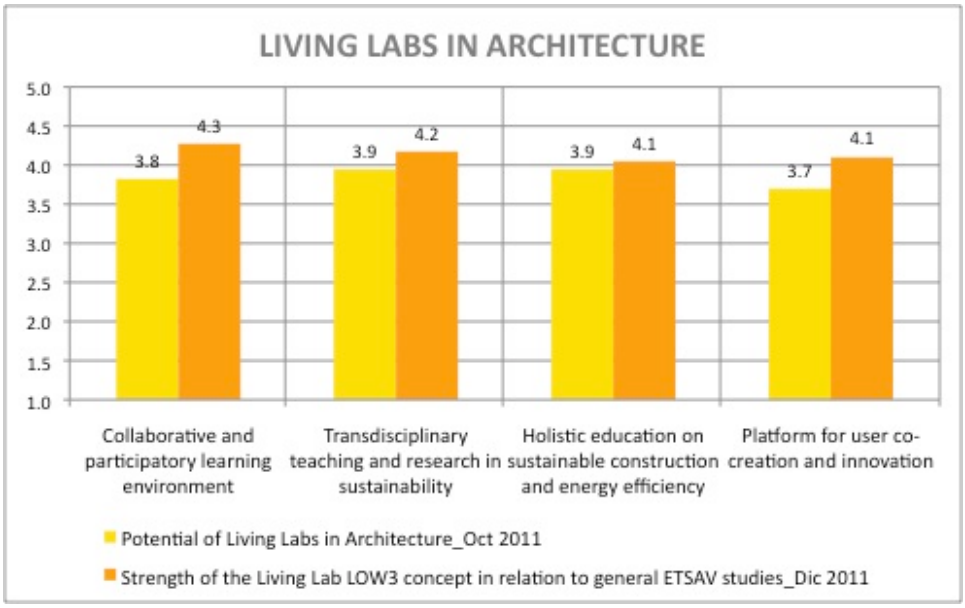


The use of virtual learning tools has been a important part of the course, and students answers reflect this through high ratings.

The concept of *Living Labs* in Architecture

Finally students have been asked their opinion about the Living Lab concept itself at the beginning and at the end of the course.

Initial question: What do you think a *Living Lab* in Architecture could stand for?
Final question: What do you think are the strengths of the *Living Lab* concept of the course in comparison to the general educational offer at ETSAV?

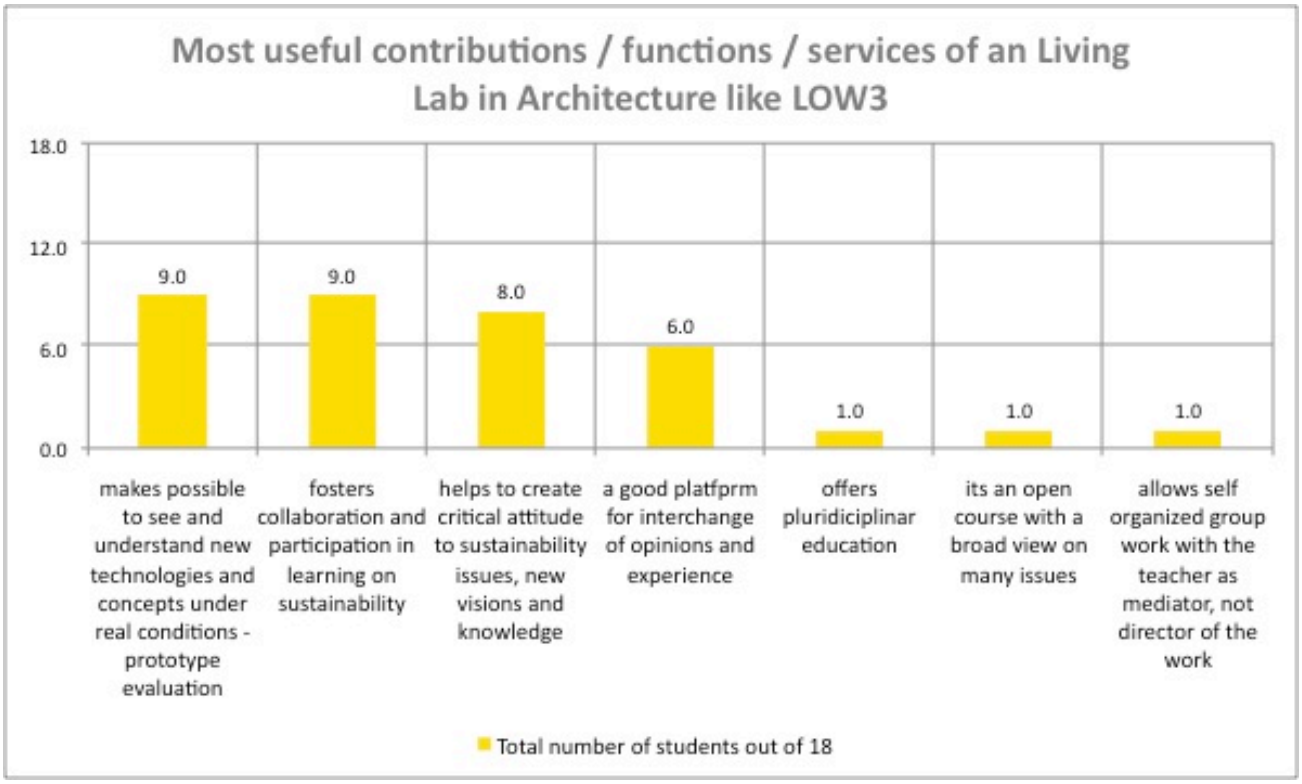


Students confirm the validity of the Living Lab concept as tool for learning at the campus and value very positively its contribution as collaborative and participatory learning environment, the transdisciplinary teaching and research in sustainability and also the holistic education in sustainability and the function of Living Lab LOW3 as platform for user co-creation and innovation.

General evaluation and personal comments

Additional questions have been raised regarding the possible contributions of the Living Lab LOW3 concept:

"How do you think could a *Living Lab* in Architecture like LOW3 contribute to improve your studies? What would be the most useful contributions / functions / services in your opinion?"



The answers reflect the critique of students about their very theory-oriented studies, with little relation to the real world and their positive opinion about Living Lab LOW3 for teaching and learning sustainability and as place for debates, interchange of opinions together with the generation of knowledge and the collaborative environment. Self-organization is mentioned positively, the broad view of the course and the role of the teacher as moderator instead of authority, leaving protagonism to students themselves.

Conclusions

I personally think that the course has improved during its development due to some improvements made like the introduction of documentaries as tools for documentation of sustainability conflicts in our everyday life, the use of Facebook as communication tool and the format of short presentations in order to maintain the course dynamic with an active participation of students.

Group dynamics also have improved and resulted in the possibility to work on a common document as course outcome of each group, linked to a group intern self-evaluation process as part this dynamic and self-organization.

The virtual learning platform MAHARA needs a lot of time to use, maintain, and mechanisms are not smart enough for using it as a easy tool for communication and shared learning.

SEEQ PRE/POST TEST

Within the **ProFI 2010-2012 program** at UPC BarcelonaTech the author participated in an educational program using **Student Experience of Education Questionnaire (SEEQ)** in order to evaluate student satisfaction for a continuous improvement of teaching concepts.
The original test has been adapted and facilitated to the participants by ICE (UPC) with permission of Herb Marsh, University of Western Sydney, Mac Arthur, Australia. (Original questionnaire see appendix 3)

Results of SEEQ questionnaires
First SEEQ questionnaire emitted to participants at 7th of November 2011.
Number of course participants: 18, answers received: 14; participation: 82.4%.

Second SEEQ questionnaire emitted to participants at 16th of December 2011
Number of course participants: 18, answers received: 18; participation: 100%.

Results:

Factor	SEEQ November 2011	SEEQ December 2011
Learning	4.13	4.06
Enthusiasm	4.23	3.96
Organization	3.48	3.41
Interaction with the group	4.44	4.47
Personal attitude	4.12	4.36
Content	4.02	4.01
Exams/Exercises	3.15	3.67
Course work	4.31	3.96
Work load and difficulty	2.60	2.74

The first questionnaire has been delivered to participants after 5 weeks of course activity, asking for their opinion about certain aspects of the course in 9 different categories.

Interpretation or results
The initial opinion of students has been very positive with an evaluation (1-5 scale) of 4.44 for the interaction with the group, 4.31 for the course work, 4.23 for the enthusiasm and 4.12 for personal attitude among the highest ranked qualities of the course. Lower ranked aspects of the course have been work load and difficulty (2.60), Exams/Exercises (3.15) and Organization (3.48).

Within the ProFI program this initial SEEQ results led and the personal experience of the first weeks, led to the implementation of an improvement plan for three main aspects of the course:

1. Improvements regarding clarity of content, definition of objectives of the course and organization
2. Improvement regarding assistance and motivation for participation
3. Improvement of teamwork mechanisms and self-organization

The SEEQ questionnaire at the end of the course activity showed little variation in the opinion of students. Some aspects have been rated a little higher like Interaction with the group 4.44/4.47, Personal attitude 4.12/4.36 and Exams/Exercises 3.15/3.67). Others have dropped slightly in its ratings, like Enthusiasm 4.23/3.96, Course work 4.31/3.96 or Learning 4.13/4.06.

CONCEPT MAPS EVALUATION

Participants have been asked to draw concept maps as outcome of the course in order to visualize their understanding of the following 3 fields:

- Living Lab LOW3 course activity: Understanding of the Living Lab concept
- ETSAV-UPC Learning Environment: Understanding of the existing Learning environment
- Sustainable Society: Understanding of

C-maps have not been used for pre-/post test evaluation, which would have given information about the positive contribution of the course to their understanding of sustainability. They were used for a final visualization of the students understanding regarding the 3 fields, in order to understand their view on the Living Lab approach, its context and the significance of SD for society

In the future C-maps could be used as an assessment tool, which gets transformed and enriched constantly, showing the evolution of student's vision and knowledge in time.
Finally this tool could be used collectively or in groups within the course, enriching the interaction and the co-creation of a common knowledge map among all participants. This implies discussion and negotiation about concepts and visions.

Appendix 1: Pictures of the course activity



Workshop activities and installation work

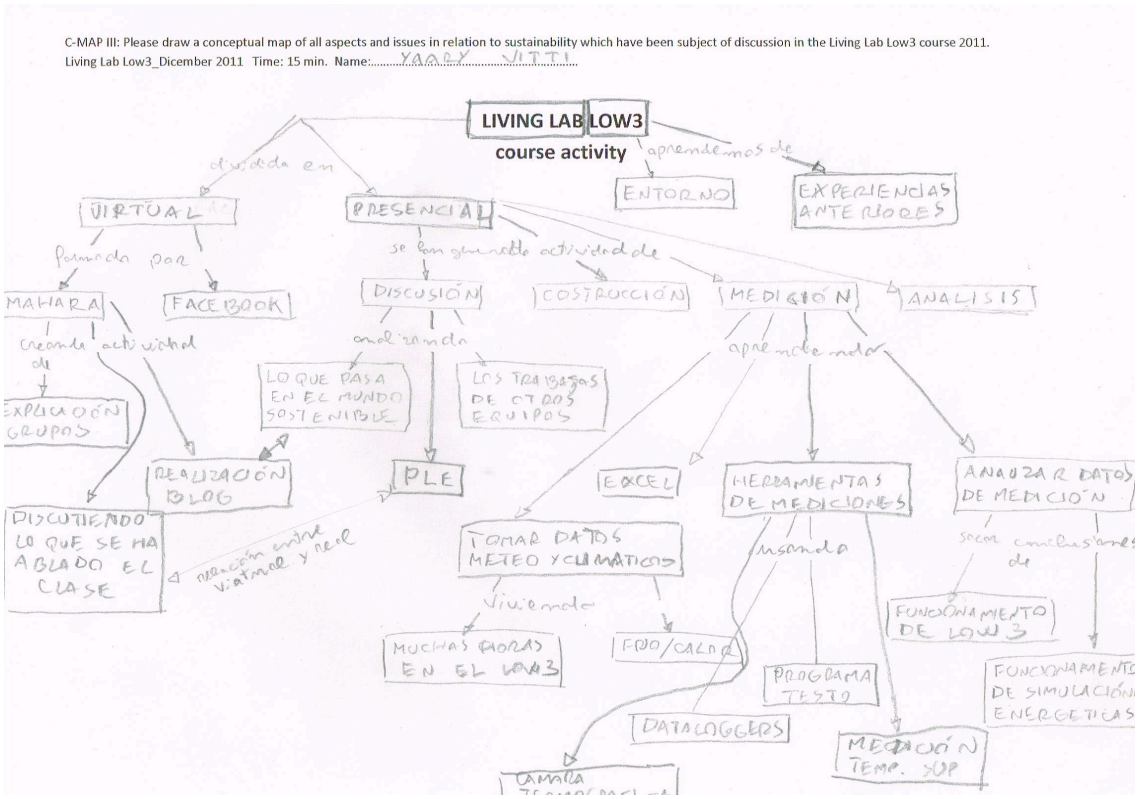


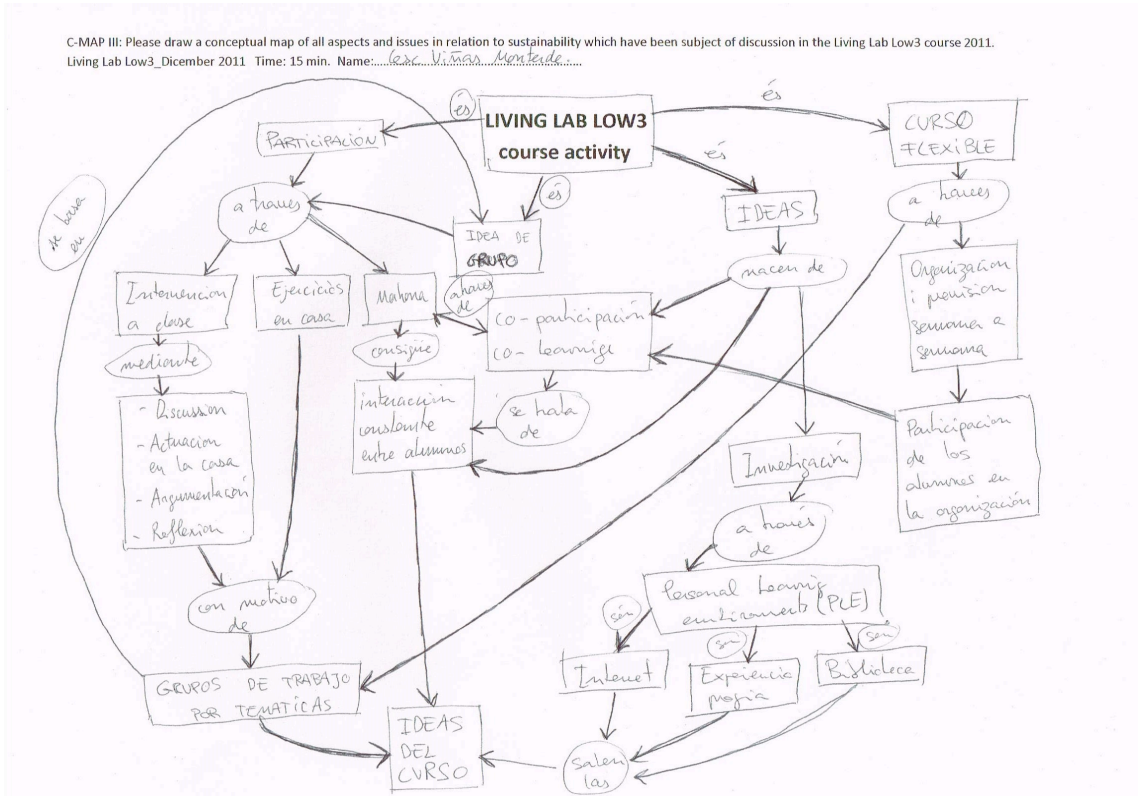
Expert's participation and group work



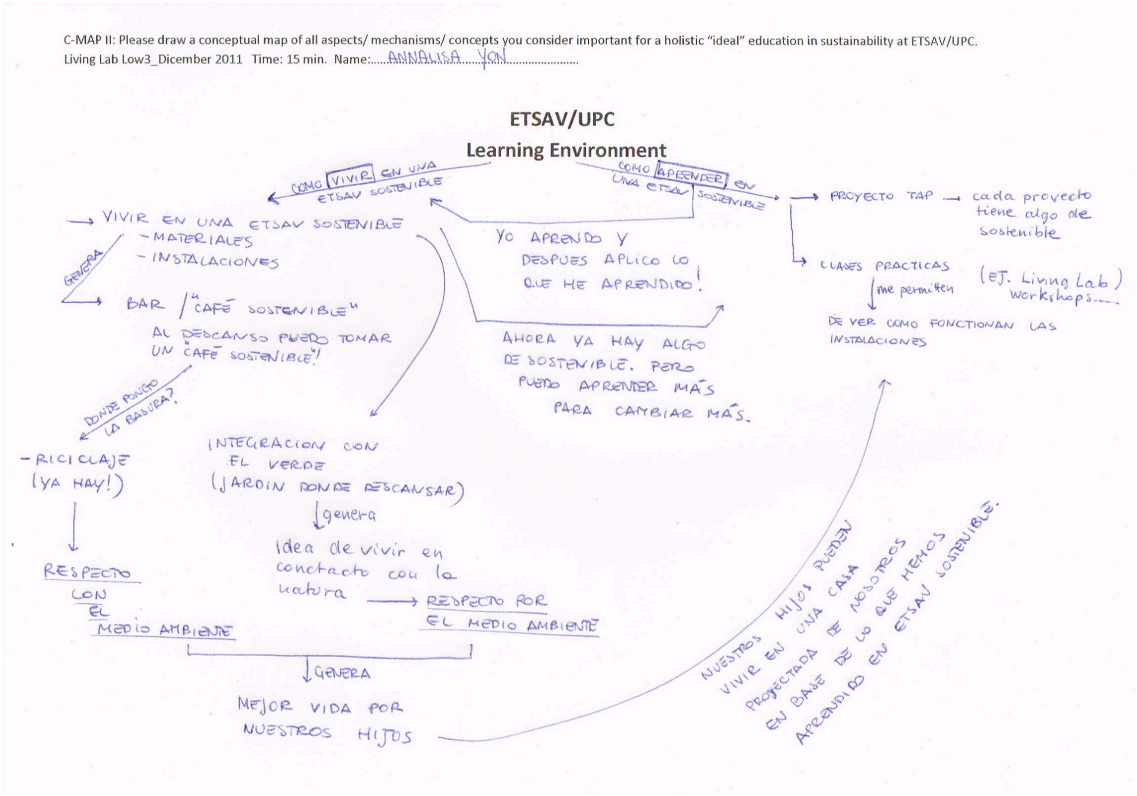
Group activities and social events

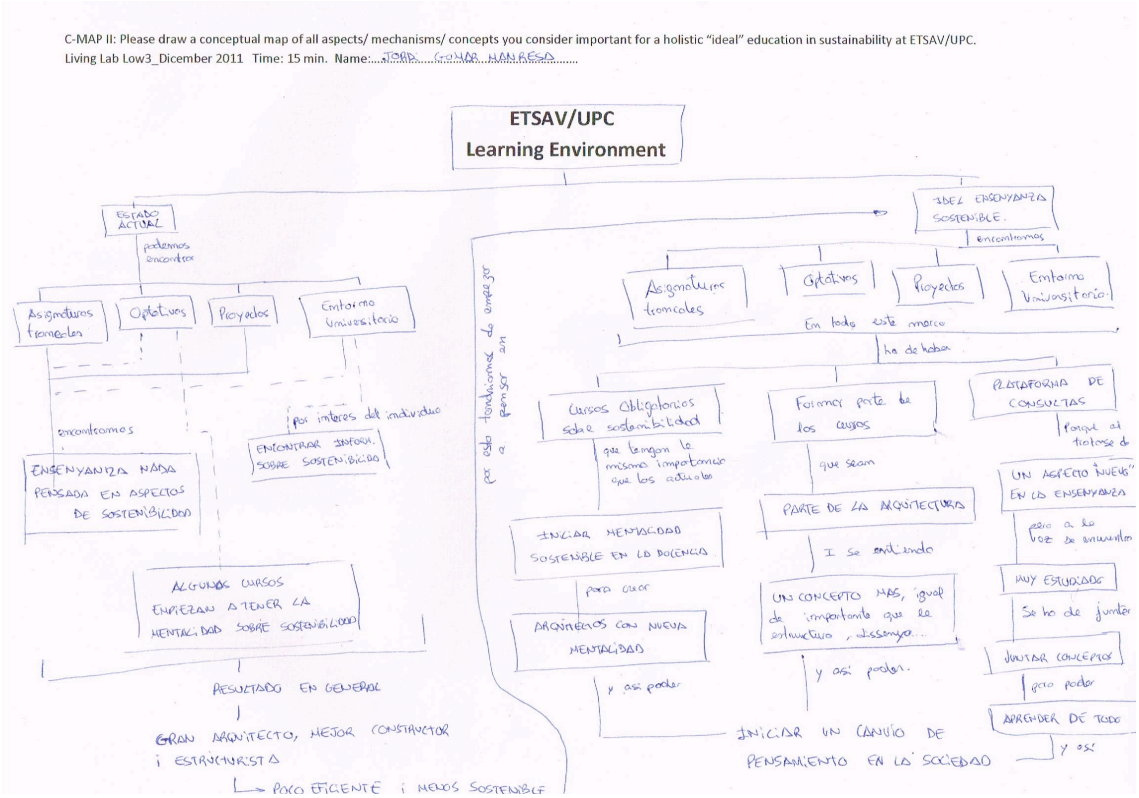
Appendix 2: Examples of concept maps



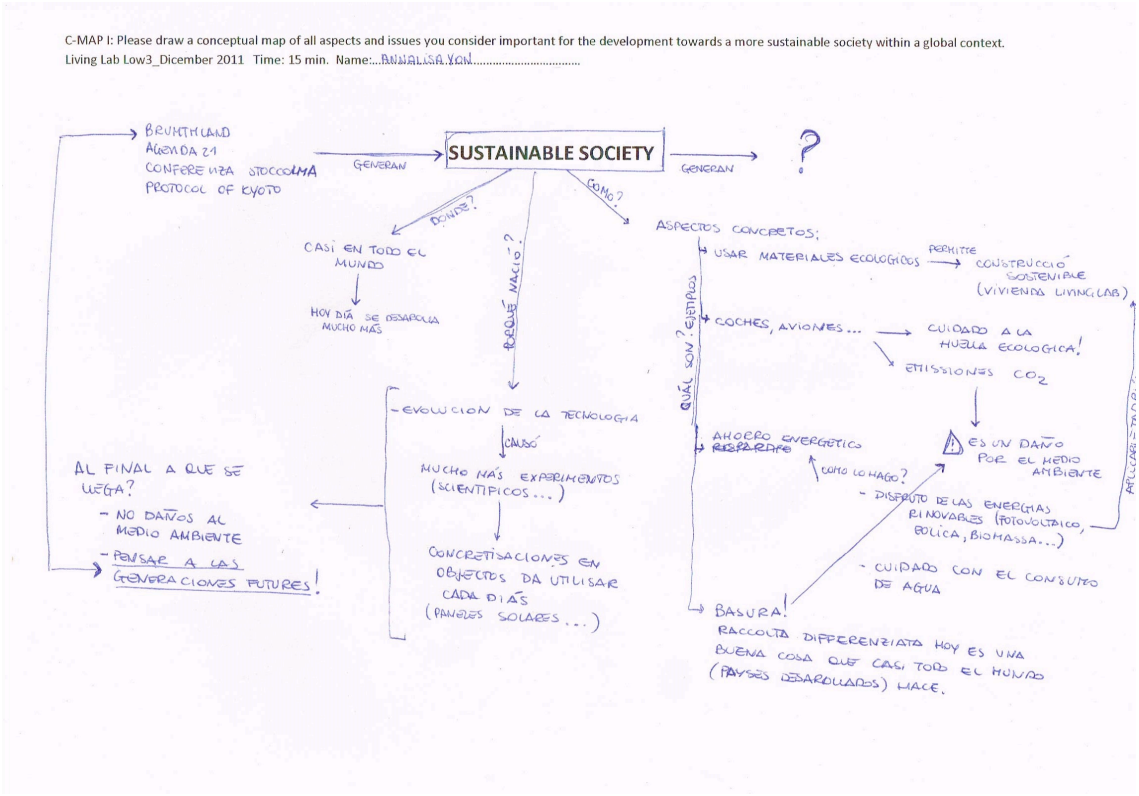


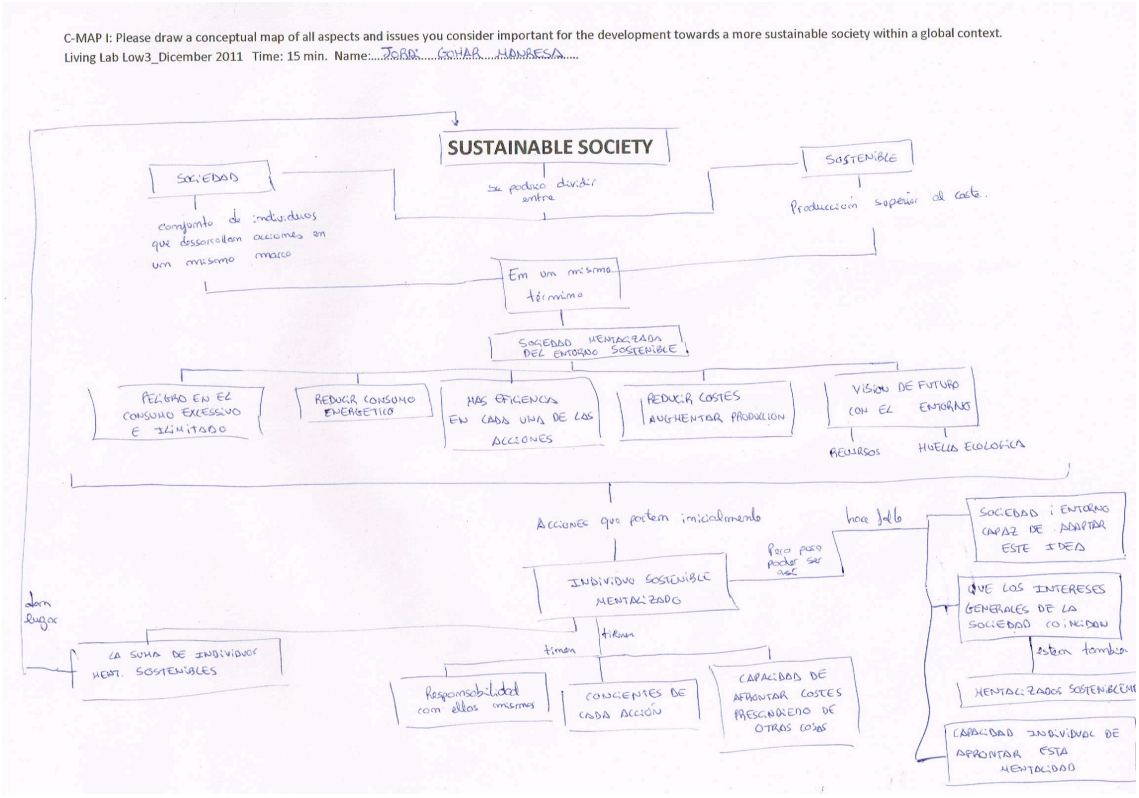
Concept Maps I: Living Lab LOW3 course activity





Concept Maps II: ETSAV / UPC Learning Environment





Concept Maps III: Sustainable Society

Appendix 3: Questionnaire SEEQ

	Very Poor desacuerdo	Poor	Moderate (Average)	Good	Very Good
LEARNING					
1. You found the course intellectually challenging and stimulating.	1	2	3	4	5
2. You have learned something which you consider valuable.	1	2	3	4	5
3. Your interest in the subject has increased as a consequence of this course.	1	2	3	4	5
4. You have learned and understood the subject materials in this course.	1	2	3	4	5
ENTHUSIASM					
5. Instructor was enthusiastic about teaching the course.	1	2	3	4	5
6. Instructor was dynamic and energetic in conducting the course.	1	2	3	4	5
7. Instructor enhanced presentations with the use of humour.	1	2	3	4	5
8. Instructor's style of presentation held your interest during class.	1	2	3	4	5
ORGANIZATION					
9. Instructor's explanations were clear.	1	2	3	4	5
10. Course materials were well prepared and carefully explained.	1	2	3	4	5
11. Proposed objectives agreed with those actually taught so you knew where course was going.	1	2	3	4	5
12. Instructor gave lectures that facilitated taking notes.	1	2	3	4	5
GROUP INTERACTION					
13. Students were encouraged to participate in class discussions.	1	2	3	4	5
14. Students were invited to share their ideas and knowledge.	1	2	3	4	5
15. Students were encouraged to ask questions and were given meaningful answers.	1	2	3	4	5
16. Students were encouraged to express their own ideas and/or question the instructor.	1	2	3	4	5
INDIVIDUAL RAPPORT					
17. Instructor was friendly toward individual students.	1	2	3	4	5
18. Instructor made students feel welcome in seeking help/advice in or outside of class.	1	2	3	4	5
19. Instructor had a genuine interest in individual students.	1	2	3	4	5
20. Instructor was adequately accessible to students during office hours or after class.	1	2	3	4	5
BREADTH					
21. Instructor contrasted the implications of various theories.	1	2	3	4	5
22. Instructor presented the background or origin of ideas/concepts developed in class.	1	2	3	4	5
23. Instructor presented points of view other than his/her own when appropriate.	1	2	3	4	5
24. Instructor adequately discussed current developments in the field.	1	2	3	4	5

Appendix 4: Questionnaire Living Lab

QUESTIONAIRE LIVING LAB LOW3 STUDENTS_October 2011

Please answer the following questions by marking numbers from 1 to 5. Please give your personal data as detailed as you feel comfortable. Thank you!
Estimated total time needed for part one of the questionnaire: 15 min.
Evaluation: 1 = not/very low 2 = little/low 3 = intermediate/regular
4 = good/high 5 = very good/very high

GENERIC DATA OF STUDENT
Name:
Nationality: _ Erasmus
Age: _ Male _ Female
Studies coursed: _ Third year _ Fourth year _ Fifth year _Final Project _ Master
Experience: _ PAUS _ CISOL Workshops _ Master Sustainability _ others:……

A. PLEASE DISCRIBE YOUR EXISTING LEARNING EXPERIENCE AND COMPETENCES

1. Please valuate your present generic competences

1. Team work, leadership, decision making 1 2 3 4 5
2. Oral and written expression, communication skills 1 2 3 4 5
3. Information management and evaluation 1 2 3 4 5
4. Interdisciplinary collaboration, transdisciplinary thinking 1 2 3 4 5

2. Please valuate your present specific knowledge in the following fields

1. Bioclimatic Architecture and Solar Buildings 1 2 3 4 5
2. Sustainable Urbanism 1 2 3 4 5
3. Energy efficiency in buildings and related technologies 1 2 3 4 5
4. Sustainability knowledge in general (energy, materials, technology, economy, society) 1 2 3 4 5

3. What is your existing experience in co-learning within university?

1. With other architecture students in design projects 1 2 3 4 5
2. With other architecture students in research works 1 2 3 4 5
3. With students of other disciplines in academic projects 1 2 3 4 5
4. Transdisciplinary teamwork related to a real project 1 2 3 4 5

4. Which virtual tools for information / learning / communication do you use normally?

1. Internet in general (Google, webs, wikis) 1 2 3 4 5
2. Special internet platforms or databases of knowledge 1 2 3 4 5
3. Social or professional networks (Facebook, LinkedIn,...) 1 2 3 4 5
4. Online learning platforms (e-learning, free online tools) 1 2 3 4 5

5. Please valuate your present general knowledge within your architecture studies

1. Architectural Design 1 2 3 4 5
2. Urbanism 1 2 3 4 5
3. Technology 1 2 3 4 5
4. General holistic knowledge (history, society, economy, politics) 1 2 3 4 5

B. PLEASE GIVE YOUR OPINION ABOUT LEARNING CONCEPTS

1. For your future work life, which competences, abilities and knowledge do you think are most important?

1.	Teamwork abilities and communication skills	1	2	3	4	5
2.	Transdisciplinary communication and understanding	1	2	3	4	5
3.	Holistic view and specific knowledge on sustainability	1	2	3	4	5
4.	Use of virtual learning environments and resources	1	2	3	4	5

2. What do you think a *Living Lab* in Architecture could stand for?

1.	Collaborative and participatory learning environment	1	2	3	4	5
2.	Transdisciplinary teaching and research in sustainability	1	2	3	4	5
3.	Holistic education on sustainable construction and energy efficiency	1	2	3	4	5
4.	Platform for user co-creation and innovation	1	2	3	4	5

3. What aspects of your current studies do you think could be significantly improved through a *Living Lab* like LOW3 at the campus?

1.	Practical construction and evaluation experience	1	2	3	4	5
2.	Transdisciplinary work experience	1	2	3	4	5
3.	Project based learning on a real building	1	2	3	4	5
4.	Interactive Learning Platform virtual/presential	1	2	3	4	5

C. PLEASE GIVE YOUR PERSONAL OPINION

1. What are the main deficits / conflicts / critics you have about your architectural studies at ETSAV / UPC?

2. How do you think could a *Living Lab* in Architecture like LOW3 contribute to improve your studies? What would be the most useful contributions / functions / services in your opinion?

Thank you / Gracies / Gracias / Merci / Danke / Grazie / Obrigado!

Appendix V: Educational Research II: Living Lab LOW3 – Innovation Seminar 2015

Documentation of seminar evaluation: Co-creation and Innovation Seminar SELECT 2015
KIC InnoEnergy - Master SELECT - Environomical Pathways for Sustainable Energy Systems

Type of activity:	**CO-CREATION AND INNOVATION SEMINAR**
Title:	**Holistic Sustainability Approach for Innovations**
Date:	5th and 7th of May 2015
Duration:	1 day
Participants:	KIC InnoEnergy Master Program SELECT first and second year students, 15 different nationalities
Background:	Engineering background (Bachelor) in different engineering disciplines

SHORT DESCRIPTION

Objectives

- Get known to a real NZEB project in the field of architecture and lifestyle and learn about a holistic view on sustainability
- Participate in and learn about guided co-creation activities for a holistic sustainability approach within an Living Lab atmosphere of user-centred, participatory research and innovation
- Develop an innovative product, service or business idea related to NZEBs (prepared exercises related to LOW3) or based on the own research approach (Innovation idea, Master thesis, etc.) focusing on an overall sustainability assessment.
- Create a holistic vision of a more sustainable society with horizon 2050.

Methodologies of Learning

Project-based Learning (PBL) and co-creation activities will be the essential methodologies applied in the seminars.

Co-creation activities based on short presentations, collective brainstorming, SWAT analysis, role-play, story-telling and similar techniques divided into a three-step process.

Use of the Living Lab infrastructure as a mixture between formal and informal learning environment, allowing the combination of creative small-scale co-creation sessions together with a personal exchange within the experimental, research-related environment of an energy self-sufficient solar house.

Creative and inspiring working atmosphere through a mixture of group work, debates, co-creation sessions and explorative and experimental activities.

Specific Seminar topics

The seminar can be focused on specific subjects related to innovation ideas and projects of the participating students, or can be generic, introducing students into specific seminar topics linked to the LOW3 concept (Bioclimatic architecture, Energy management in buildings, HVAC systems, Photovoltaic technologies, Solar thermal systems amongst others)

Intended Learning Outcomes

- **Creativity** of students will be fostered through the participation in co-creation processes applied to each individual project, enhancing the ability to think beyond boundaries and systematically explore and generate new ideas
- **Innovation skills** will be trained enhancing students ability to use knowledge, ideas or technologies to create new or improved products, services, processes or business models.
- **Entrepreneurship skills** will be enforced through the support of students in collectively developing their innovation ideas towards feasible business approaches.
- **Research skills** will be trained through the project-based approach of the seminars, focused on the investigation of new venture creation and its validation through a cross-disciplinary analysis.
- **Intellectual transforming skills** will be attended through transforming practical experiences at the Living Lab infrastructure into research problems and challenges within an experimental and non-formal learning environment.

- **Leadership skills** will be fostered through the specific group dynamics at the Living Lab seminars based on co-creation techniques and accelerated decision-making processes.
- **Value Judgment** of students will be enhanced through the individual and collective appreciation of ethical, scientific and sustainability challenges of each presented project.

Program

10.00h	Welcome and short visit to the ETSAV campus	ETSAV Campus
10.30 h	Introductory presentation to ETSAV campus and its buildings (PAUS Agora)	PAUS Agora
11.00 h	Introductory seminar presentation and Living Lab Concept (PAUS Agora)	PAUS Agora
11.30 h	Coffee break – optional visit to the SOLAR CUBE Laboratory	
12.00 h	Visit, exploration and group work at LOW3 prototype (5 thematic groups)	Living Lab LOW3
13.30 h	Lunch break (self-service at the dining hall)	
15.00 h	Experts input on innovation – Valldoreix Green Power (VGP) / CFV systems	PAUS Agora
16.00 h	Group work on innovation ideas with holistic sustainability approach (LOW3)	Living Lab LOW3
17.00 h	Final presentations, discussion and collective feedback (15min/group)	PAUS Agora
18.30 h	End of seminar	

CO-CREATION EXERCISE: TRANSITION TOWARDS A MORE SUSTAINABLE SCENARIO 2050

Objective: Vision-building and story-telling regarding a more sustainable world in 2050 through a 3-step analytic and creative co-creation process in groups of 3 to 5 students, creating a vision based on the implementation of a specific technology/system innovation for Nearly Zero Energy Buildings (NZEBs) in one of the following fields:

Bioclimatic performance: Buildings and natural resources / building envelopes / passive systems
Energy management: Building control systems and human-building interaction / smart grids
HVAC system: Indoor climate and comfort / compact systems
Photovoltaic system: Energy self-sufficiency and storage / grid options / building integration
Solar thermal system: Energy self-sufficiency and storage / grid options /building integration

3-step working structure:

A_MINDMAP (CONCEPT + ANALYSIS): Brainstorming of all aspects regarding environmental, economic and social sustainability related to the chosen focus area, taking LOW3 as example (Collective brainstorming, complex mind map – see examples, poster format, time: 30 min.)

B_TABLE (FACTS + OUTLOOK): Technological state of the art analysis, existing concepts and desirable developments towards 2050 (Systemic technology analysis, future outlook, table format, time: 30 min.)

C_STORY (VISION + IDEAS): Transport your audience through your vision towards a more sustainable world in 2050, telling the story of a person, within a house (LOW3 2050), within a community, within a city… , including your systemic technology outlook (Story-telling, visual appealing presentation, poster format, time: 45 min.)

EVALUATION AND OUTCOMES

PERSONAL EVALUATION

The seminar has been fruitful; the foreseen program has been fulfilled, with an active participation of students (total assistants: 20) who showed a good existing background in renewable energies.

The **introductory presentation session** and 'warm-up' discussions on sustainability created a first common background for the participatory approach of the seminar.

The **exploration of the Living Lab LOW3 prototype solar house** introduced students in the concept of a Nearly Zero Energy Building, its applied technologies, and all related sustainability concepts like low impact building materials, concepts of modularity and co-housing, adapted industrialized construction systems, energy management and bioclimatic architecture, amongst others, with an holistic view on solutions for a more sustainable lifestyle.

The **debate session with an invited entrepreneur** and expert in the renewable energy sector has been received very positively, giving a first hand impression about the complexity of converting an idea into a marketable product or service. A lively debate about entrepreneurship, innovation, business models, venture capital and business angels for start-ups and corresponding digital platforms, as well as necessary personal competences of entrepreneurs rounded up this session.

The **mind-map exercise (step 1)** has brought a first approach to the complexity of interrelated environmental, economic and social aspects related to each technology.

The **state-of-the-art analysis (step 2)** of each technology has been carried out generically with limited capacity of analysis, data collection and preparation. Desirable future developments have been described.

The **story-telling and related vision building exercise (step 3)** has generated interesting futures scenarios with the horizon 2050 with some interesting and creative approach to the integration of technology into every-day life. Almost all scenarios combined a technological vision within a holistic context of society, lifestyle, including environmental aspects and to a limited extend economic considerations.
Due to the character of the exercise and the specific demand of opening up minds, also "funny" or "futuristic" elements (e.g. the 'energy stick' as a type of energy-pen drive for storage) have been part of the developed scenarios. These outcomes might seem little academic or serious at a first glance, but at a second view, creativity and the search for so fare unexplored concept and 'out of the box thinking' find its place in the very heart of innovation theory.

The **relation between available time and outcomes** can be seen very positively, although many aspects regarding a holistic approach to sustainability would have needed more time for debate. Group dynamics and co-creating requires time for discussion and reduces "output" in form of produced material, which can be seen critical. Nevertheless debates and group discussions are basic features of this type of co-creation and innovation activity and contribute essentially to its positive impact regarding students' intrapersonal competences.

The **overall objective** of transmitting to and exercising with engineer students a holistic, transdisciplinary view on sustainability, analysing and understanding technology within its environmental, economical and social context, has been achieved satisfactorily from the point of view of the author in its role as organizer of the event.

POST-ACTIVITY QUESTIONNAIRE TO PARTICIPANTS

In order to evaluate the results of the seminar and gather participants' feedback about applied methodologies, achieved learning outcomes and the living lab concept itself, an **online questionnaire** has been used.

From an overall announced student group of 53, finally 39 (19 first year students and 20 second year students) assisted the seminar, in two separated sessions, but with the same course format.

The **background of the participants,** with an average age of 25 years, was the following:

- Mechanical Engineering 14
- Industrial Engineering 2
- Energy Engineering 7
- Chemical Engineering 4
- Electronic Engineering 3
- Civil engineering 1
- Material Scientist 1

32 out of 39 students answered the questionnaire, which corresponds to an **answer rate of 82%** of students giving their feedback about the activity.

The questionnaire has been send the day after the seminar by email, with 2 follow-up emails as reminders in the following 2 days.

The course activity has received all over a very positive evaluations by the participating students, evaluating the activity with an **overall rating of 4.19** on a 1-5 scale.

The **PLACE** has been rated with average **4.15**, valuating positively the Living Lab LOW3 itself as a place to meet and work (4.38) the resources and working materials (4.13) and the overall commodity, referring to space, seats, light, catering (3.94).

The applied **METHODOLOGY** has been rated average **4.24**, with specific ratings for the Living Lab methodology consistent in exploration, presentations, brainstorming and co-creation activities (4.38), the moderation of the sessions and co-creation activities (4.22), the collective brainstorming and co-creation activities (4.22) and the specific contribution of invited experts (4.53).

The **TIME FRAME** has been rated average **4.04**, with specific ratings for sufficiency of time available for discussion and development of ideas (3.91), the total duration of the event of 1 day (4.00) and the balance between explorative activities, group work, presentations and open discussions (4.22).

Regarding the **LEARNING EXPERIENCE** specific the following specific areas have been evaluated:

The **transmission of specific knowledge** in five main fields of the seminar has been rated average **3.64**, with specific ratings for knowledge regarding Sustainable Architecture and Nearly Zero Energy Buildings (3.88), Renewable Energy Technologies (3.13), Energy efficiency in buildings (3.47), Holistic understanding of sustainability (environment, technology, economy, society) (4.06) and Entrepreneurship and Innovation in the Renewable Energy Sector (3.66).

The **improvement of 5 main competences, skills and abilities** which the seminar pretends to foster has been rated average **3.93**, with specific ratings for teamwork and communication (3.97), Critical thinking (3.81), System thinking (3.84), Scenario building and Storytelling (4.09) as well as Creative and holistic approach to innovation (3.94).

The **strength in 5 identified areas regarding teaching and learning sustainability** of the Living Lab LOW3 concept in comparison to other educational offers has been rated average **3.94**, with specific ratings for the

collaborative and participatory learning environment (3.94), the transdisciplinary teaching and research in sustainability (3.88), the holistic approach to sustainable life style and energy efficiency (4.09), the experience-based and user-centred research environment (1:1 prototype) (4.06), and the open platform for co-creation and innovation activities (4.00).

Asked about the **results of the seminar**, participants rated to which degree the seminar has been useful for them (4.19), to which degree their holistic understanding of sustainability has been improved (4.09), to which degree they have been able to generate innovative ideas (3.78) and to which degree they could benefit from networking with other participants (3.75).

A final and **overall evaluation of the seminar** resulted in a rating of **4.19**.

Asked for **comments and recommendations** for future seminars, students mentioned:

- Too little time for brainstorming and group work
- Extending the overall duration to several days
- More contact with students of architecture

INTERPRETATION OF RESULTS

The seminar has received an exceptional high rating in almost all aspects. It seems that the expectation of students have been met to a very high degree with an **overall rating of 4.19.**

Regarding the PLACE, the **Living Lab itself, as a place to meet and work has been rated 4.38,** which confirms ones more that the architecture of this prototype building serves perfectly as a space for seminars or similar activities, which draw on creativity, communication and innovation, offering an inspiring conceptual environment, but also a comfortable place, with an appealing design, a useful special concept and equipment for fruitful and inspirational work. The location in the “green” part of the campus, its sunny terrace and the good weather during the seminar might contribute to this overall positive experience.

Regarding the applied METHODOLOGY the **expert contribution has been rated 4.53**, showing a full satisfaction of students with the possibility to speak to an renewable energy entrepreneur who transmits his experience and shares his specific knowledge not only about the energy sector but specifically about how to be successful in new business creation, innovation in product and business models as well as

Regarding the TIME FRAME of the seminar, the **balance between explorative activities, group work, presentations and open discussions has been rated 4.22,** showing that students perceived the structure and content of the seminar program as the right mixture between different working formats and experiences. This contributed to the overall success, as it kept students motivated and dynamic during the whole day.

Regarding the LEARNING EXPERIENCE and asked for the transmission of knowledge through the seminar, the **holistic understanding of sustainability (environment, technology, economy, society) has been rated 4.06**, which shows that the objective of the seminar of a ‘holistic approach to sustainability’ has been fully achieved. Knowledge transmission in the field of **renewable energy technologies has been rated 3.13**, reflecting the much lower focus on specific technologies, and the background of participants, trained already widely in the field of renewable energy technologies as engineers.

Teamwork and communication (3.97) as well as **Scenario building and Storytelling (4.09)** have been rated very positively in the field of competences, skills and abilities, validating the applied methodologies and tools of the seminar. Story telling methodology is used for creating holistic and complex future scenarios, an ability which pretends to approach participants to an holistic understanding of the interdependence between technology, lifestyle and sustainability.

Asked for the strength of the Living Lab concept, again the **holistic approach to sustainable life style and energy efficiency (4.09)** and the **experience-based and user-centred research environment (1:1 prototype) (4.06)** have been rated highest, showing the appreciation of participants for this type of teaching and learning approach. This gets also reflected in some final comments of participants, asking for more **contact to architecture students** during the seminar, as well as the **extension of the overall duration**, seemingly based on the perception of a certain lack of time for group work and discussions.

ACHIEVED LEARNING OUTCOMES

The application of a **3-step working structure** consistent in the elaboration of mind maps (concept + analysis), tables (facts + outlook) and a story (vision + ideas) regarding to a specific technology or concept applied in the LOW3 solar house, allowed the achievement of the following learning outcomes:

The elaboration of mind maps opened up the discussion within the individual working groups **dealing with complexity** related to the concept of sustainability, opened up minds to **system thinking** and allowed **creative and communicative group work.**

The elaboration of a table, resuming the state of the art of a certain technology or concept and creating an outlook regarding its further development fostered the capacity of **information generation and management,**

Finally the development of a story, which reflects a future scenario (2050) of a technology or concept, allowed to improve the capacity of participants in the field of **vision building, story telling**, and abilities of **creativity** and **communication** through the graphic representation (posters) and presentation (oral communication) in front of an audience (other participants).

Regarding the *intended learning outcomes*, announced in the seminar program, **entrepreneurship skills and research skills** have been trained differently, namely through the discussion with an entrepreneur in the energy sector and some limited technology research, as due to the time restrains of the course, individual projects of participants could not be in the focus.

SPECIFIC LEARNING OUTCOMES REGARDING ESD

Regarding knowledge, skills and competences related to ESD the following specific learning outcomes could be mentioned:

- Creativity: Creation of innovative ideas (energy stick,)
- Cross-disciplinary thinking: Architecture, society, energy, environment, economy
- System thinking: technology impact at all levels, scales, and over time
- Entrepreneurship thinking: idea to product, product to market, business creation

Participants' evaluations through the questionnaire are in line the achieved learning outcomes described above. They mention very positively the trans-disciplinary approach towards a holistic view on sustainability, which is the main underlying concept of the course.

PERSONAL OBSERVATIONS

Differences between first and second year Master students can be described with a more receptive attitude of younger students to get involved in some non-orthodox or unknown methodology, which needs **openness and a willingness for creativity experimentation**. This resulted also in a somehow more consistent outcome regarding concept maps, technology analysis and scenario building. Nevertheless these interpretations strongly depend on the individual participants in each activity, their personal commitment to the course and therefore cannot be generalized.

OUTLOOK

The 1-day seminar for 'Holistic sustainability approach to innovation' has been held 5 times since 2013. It forms part at the date of writing of 2 different Master Programs and the KIC PhD School. Its concept has evolved towards an efficient organized workshop activity, which generates a valuable although small-scale contribution to a holistic education of engineers with careers in the field of renewable energy systems. Its trans-disciplinary and participatory teaching and learning approach is well appreciated by participants. The seminars will also in the future form part of the core activities of Living Lab LOW3, constantly improving its formats, applied methods and tools.

Annex 1: Pictures of the seminar



Visit to ETSAV campus infrastructure: BIPV Laboratory “Solar Cube”



Introductory session at PAuS Agora platform



Group working session at Living Lab LOW3



Group working session at Living Lab LOW3



Group working session at Living Lab LOW3

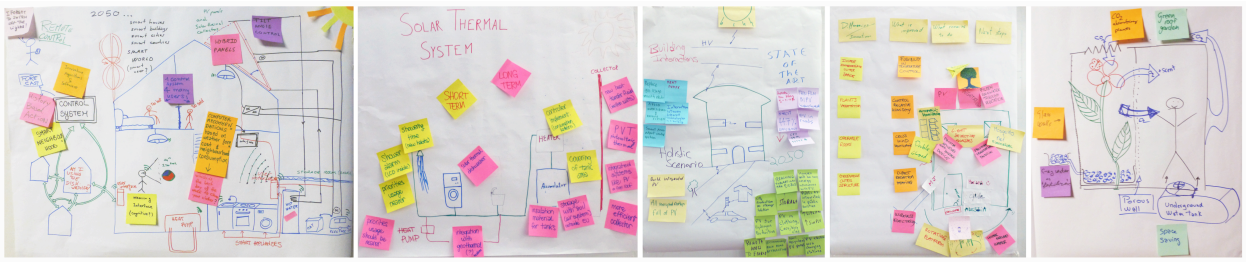


Group presentations at PAuS Agora plaform



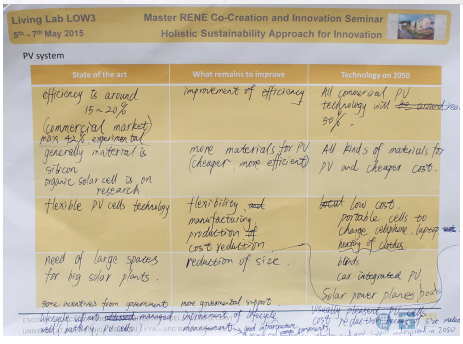
LOW3 prototype exploration

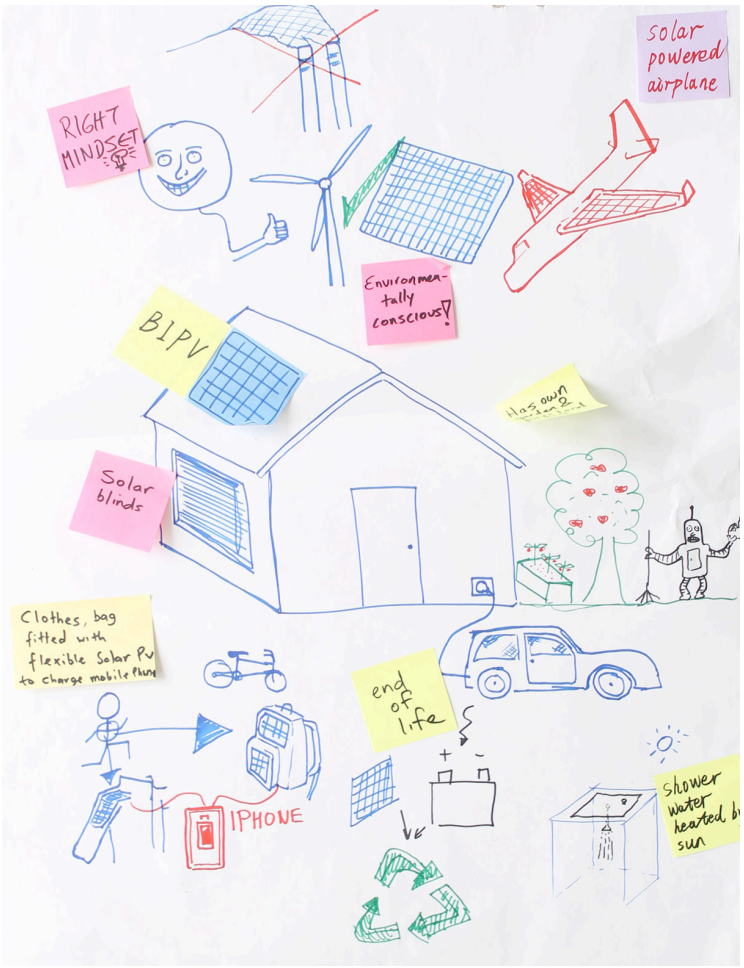
Appendix 2: Produced material (mind maps, tables, scenarios)



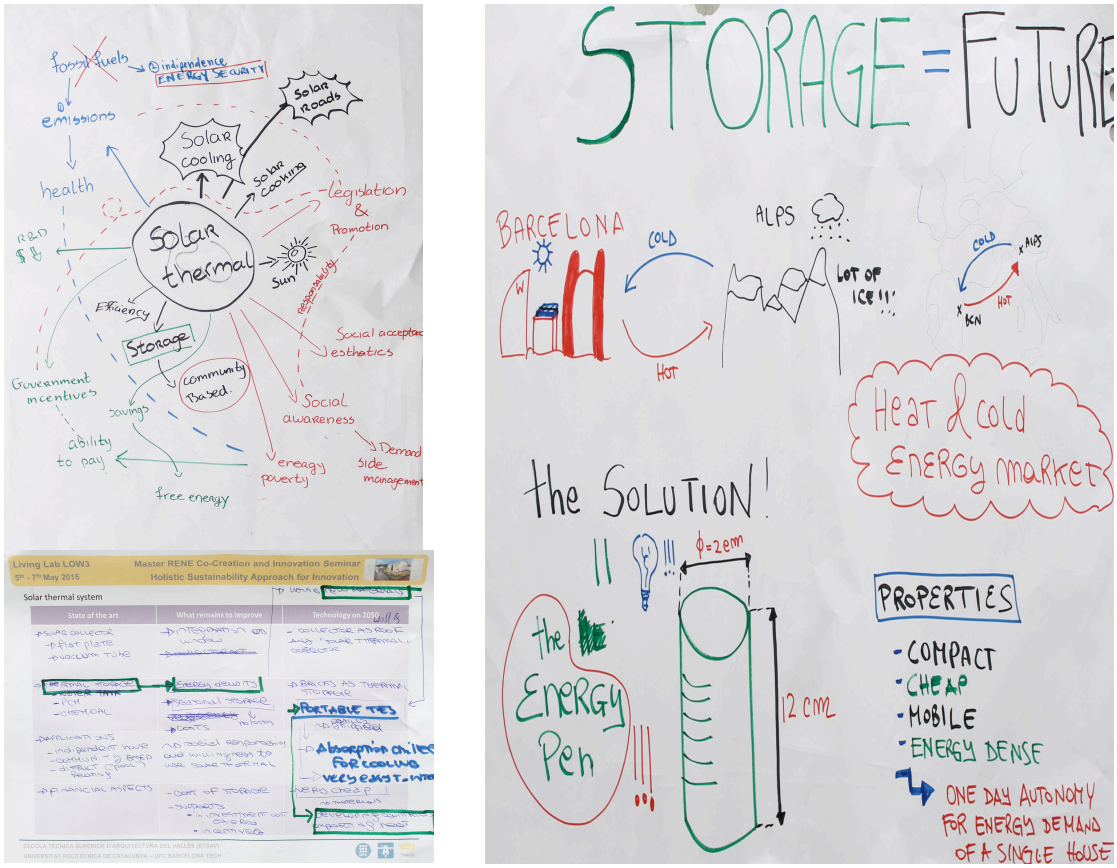
Co-creation exercises during group working sessions



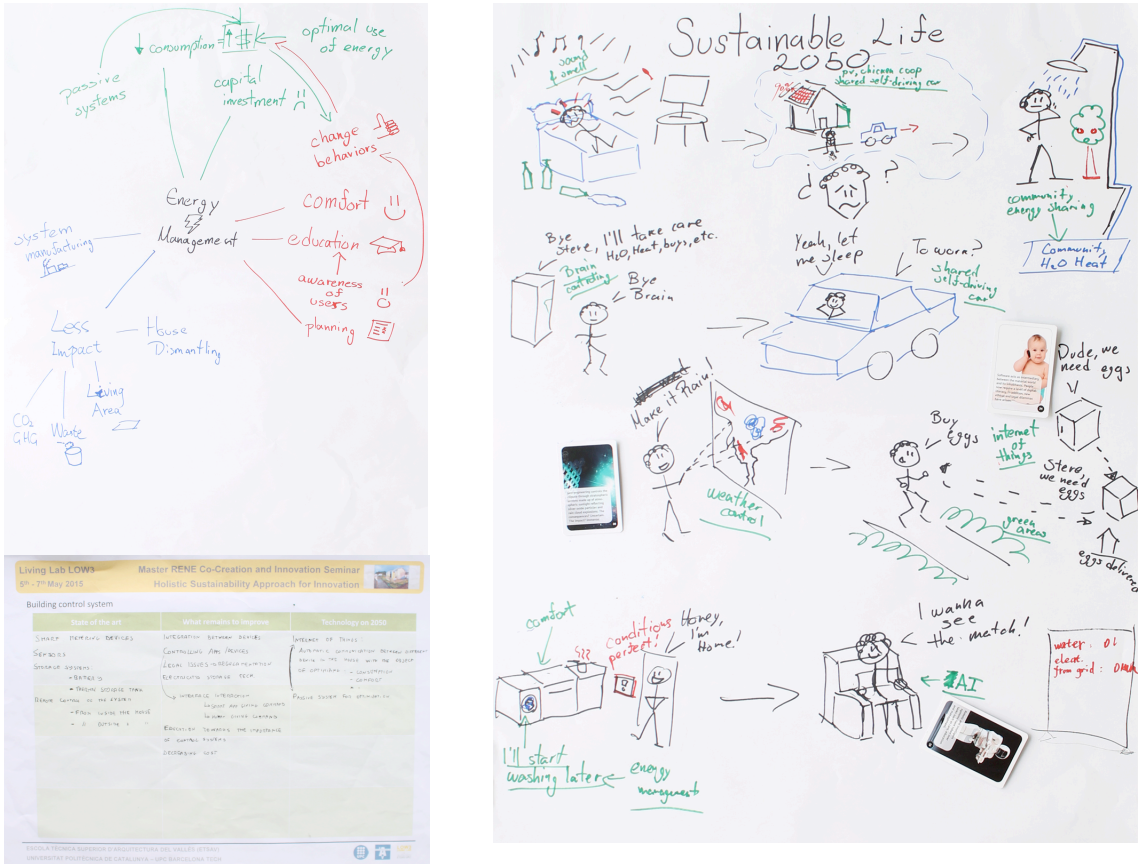




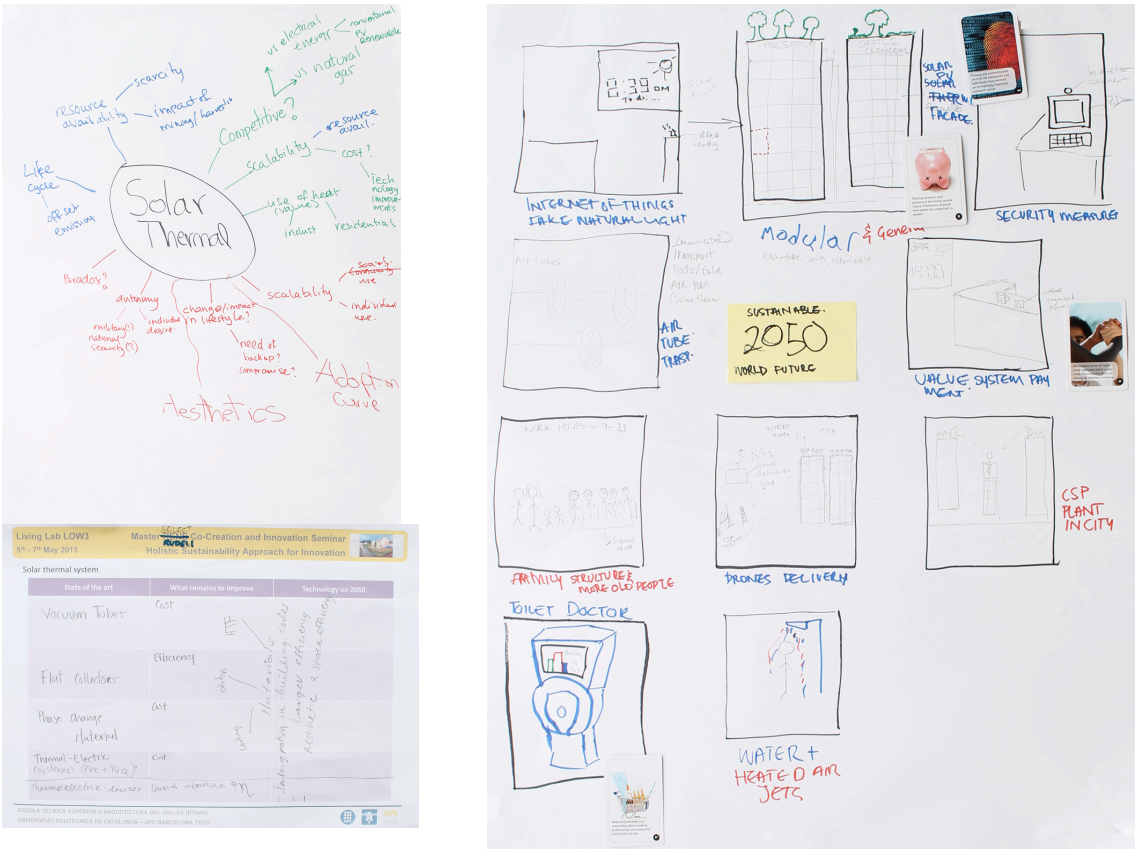
Outcomes PV group – SELECT seminar 1



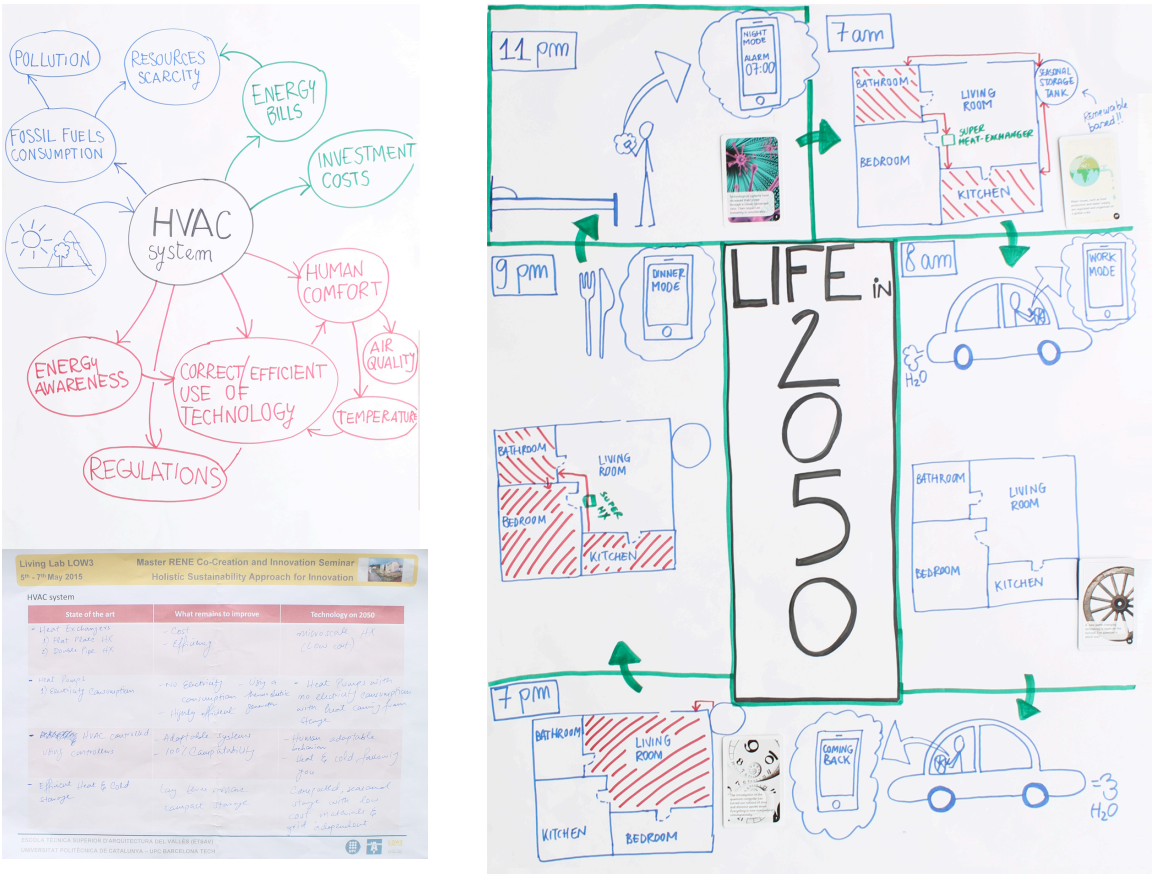
Outcomes Solar Thermal group – SELECT seminar 1



Outcomes Energy Management group – SELECT seminar 2



Outcomes Solar Thermal group – SELECT seminar 2



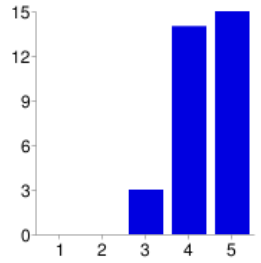
Outcomes HVAC group – SELECT seminar 2

Appendix 3: Questionnaire Living Lab LOW3_Innovation Seminar May 2015_Master SELECT

Detailed results of an online questionnaire to participants of the Innovation Seminar Master SELECT held at 5th and 7th of May 2015 at Living Lab LOW3.

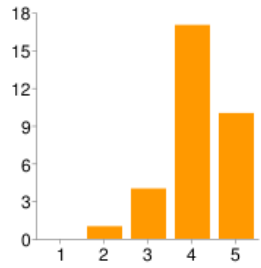
PLACE

1.1. How do you evaluate the place of the seminar (the Living Lab LOW3 itself as place to meet and work)?



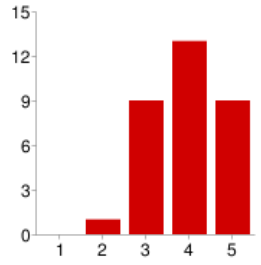
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	3	9.4%
4	14	43.8%
5	15	46.9%
AVERAGE EVALUATION: 4.38		

1.2. How do you evaluate the resources and equipment available for the seminar (informatics, working material etc.)?



Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	4	12.5%
4	17	53.1%
5	10	31.3%
AVERAGE EVALUATION: 4.13		

1.3. How do you evaluate the comfort and commodity during the seminar (space, seats, light, catering)?



Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	9	28.1%
4	13	40.6%
5	9	28.1%
AVERAGE EVALUATION: 3.94		

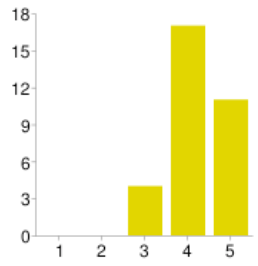
Comments about the PLACE:

- It's a good place
- Very cool concept! Success
- Everything was very nice, except the laptop which got frozen and the cafeteria offer, ☺
  the facilities were adapted for the number of participants and the type of activities.
- The is really cool compared with surroundings. It is also a impressive experience to workin such an innovative building.
- I would suggest may be for the activity is to make it more hands on by assigning students
  to physically build something with the materials given and then relate it to the energy sector.
- The place is beautiful
- The location was very nice. I enjoyed the open classroom
- Nice environment
- The living lab feels very cozy environment

- Was very interesting and more comfortable than i expected
- Place was fine and comfortable for the work.

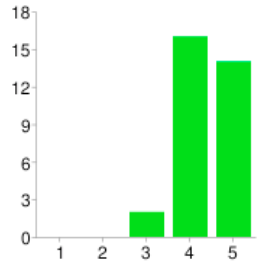
METHODOLOGY

2.1. How do you evaluate the Living Lab methodology (exploration, presentations, brainstorming, co-creation activities)?



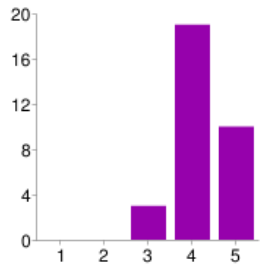
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	4	12.5%
4	17	53.1%
5	11	34.4%
AVERAGE EVALUATION: 4.22		

2.2. How do you evaluate the moderation of the seminar (moderation of the sessions, co-creation activities)?



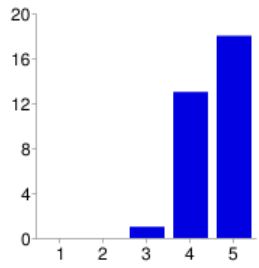
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	2	6.3%
4	16	50%
5	14	43.8%
AVERAGE EVALUATION: 4.38		

2.3. How do you evaluate the process of collective brainstorming and co-creation of ideas (efficiency, material and methods applied, outcomes)?



Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	3	9.4%
4	19	59.4%
5	10	31.3%
AVERAGE EVALUATION: 4.22		

2.4. How did you find the experts contribution to the seminar (quality, content, interaction with participants)?



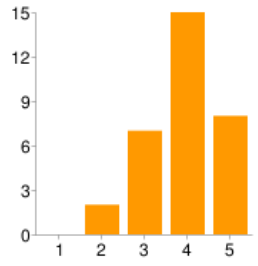
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	1	3.1%
4	13	40.6%
5	18	56.3%
AVERAGE EVALUATION: 4.53		

Comments about METHODOLOGY:

- It was fun and interesting
- It was a very interesting experience and workshop. It was mainly focused on the built environment field, which is not properly a field that as engineers we are confident with, and therefore i think that I learned a lot and had a very interesting time. it was not boring at all, so the methodology helped to make it interesting and dynamic!
- maybe a little more examples of various other technologies and how they're being applied
- It is nice to have brainstorm with my teammates. The idea to think of the use in 2050 on specific technology is nice.
- Good
- The methodology was very good, but sometimes I felt a bit lost on the final objective of the activity, namely the history, in which I wasn't quite sure on how to proceed and which aspects to take into account, if only my theme or all of them
- There is a gap between the mental map and the vision for 2050
- Well conducted
- Bigger screen for the presentation to see better would be appreciated.

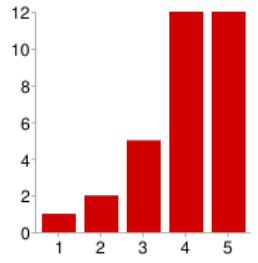
TIME FRAME

3.1. Did you have enough time to discuss and develop a project idea?



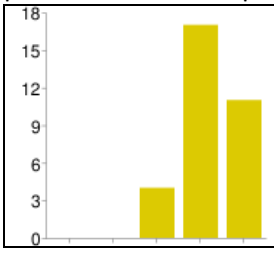
Value (1-5)	Answers	Percentage
1	0	0%
2	2	6.3%
3	7	21.9%
4	15	46.9%
5	8	25%
AVERAGE EVALUATION: 3.91		

3.2. How do you evaluate the total duration of the event (1 day)?



Value (1-5)	Answers	Percentage
1	1	3.1%
2	2	6.3%
3	5	15.6%
4	12	37.5%
5	12	37.5%
AVERAGE EVALUATION: 4.00		

3.3. Do you think the relation between explorative activities, group work, presentations and open discussion has been balanced?



Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	4	12.5%
4	17	53.1%
5	11	34.4%

	AVERAGE EVALUATION: 4.22

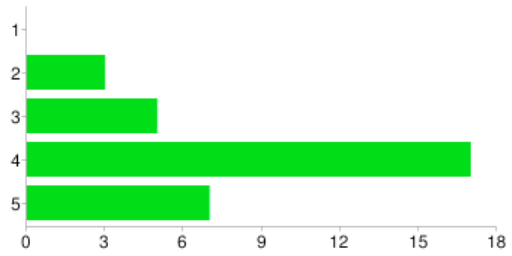
Comments on TIME FRAME:

- Okay
- 1 day is not enough
- Enough
- Time for teamwork is a little too limited.
- It was good timing
- I think that it was a cool experience, but maybe the part of the project working could have
- been explored better within the frame of - days. especially for people who are not expert in the field.

LEARNING EXPERIENCE

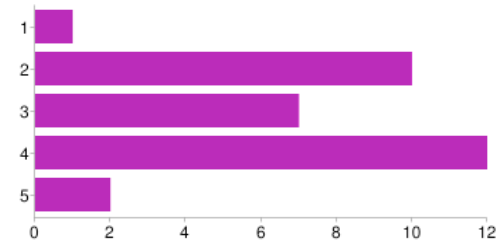
1. Which kind of specific knowledge has been transmitted in the course?

Sustainable Architecture and Nearly Zero Energy Buildings



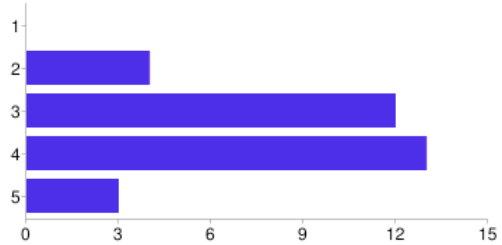
Value (1-5)	Answers	Percentage
1	0	0%
2	3	9.4%
3	5	15.6%
4	17	53.1%
5	7	21.9%
AVERAGE EVALUATION: 3.88		

Renewable Energy Technologies



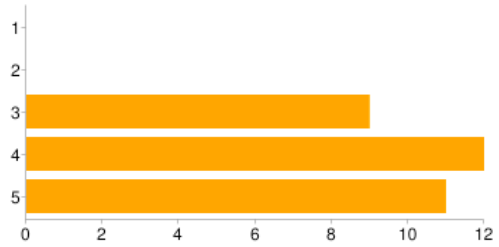
Value (1-5)	Answers	Percentage
1	1	3.1%
2	10	31.3%
3	7	21.9%
4	12	37.5%
5	2	6.3%
AVERAGE EVALUATION: 3.13		

Energy efficiency in buildings



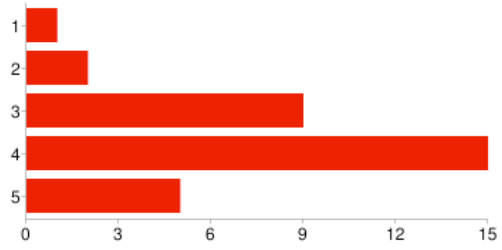
Value (1-5)	Answers	Percentage
1	0	0%
2	4	12.5%
3	12	37.5%
4	13	40.6%
5	3	9.4%
AVERAGE EVALUATION: 3.47		

Holistic understanding of sustainability (environment, technology, economy, society)



Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	9	28.1%
4	12	37.5%
5	11	34.4%
AVERAGE EVALUATION: 4.06		

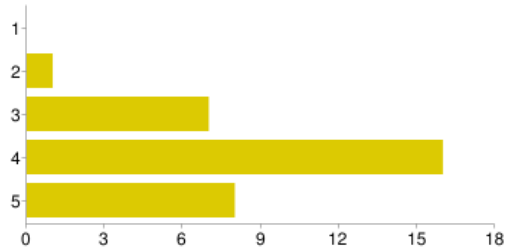
Entrepreneurship and Innovation in the Renewable Energy Sector



Value (1-5)	Answers	Percentage
1	1	3.1%
2	2	6.3%
3	9	28.1%
4	15	46.9%
5	5	15.6%
AVERAGE EVALUATION: 3.66		

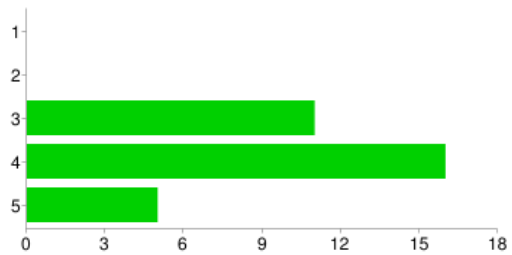
2. To which degree have been fostered the following competences, skills and abilities?

Team-working and communication



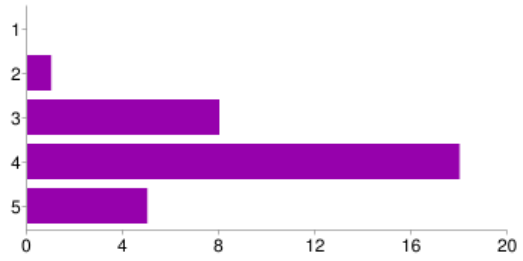
Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	7	21.9%
4	16	50%
5	8	25%
AVERAGE EVALUATION: 3.97		

Critical thinking



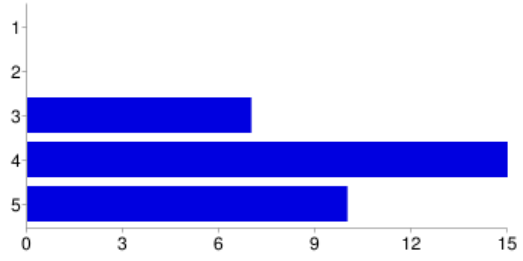
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	11	34.4%
4	16	50%
5	5	15.6%
AVERAGE EVALUATION: 3.81		

Systems thinking



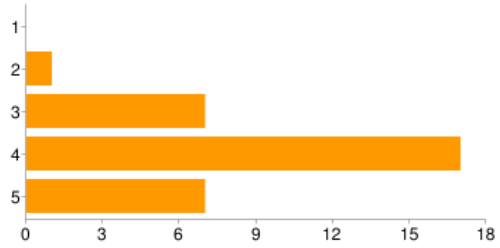
Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	8	25%
4	18	56.3%
5	5	15.6%
AVERAGE EVALUATION: 3.84		

Scenario building and story telling



Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	7	21.9%
4	15	46.9%
5	10	31.3%
AVERAGE EVALUATION: 4.09		

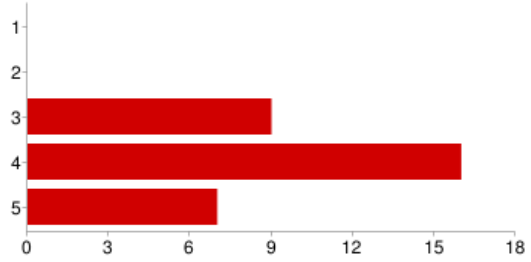
Creative and holistic approach to innovation



Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	7	21.9%
4	17	53.1%
5	7	21.9%
AVERAGE EVALUATION: 3.94		

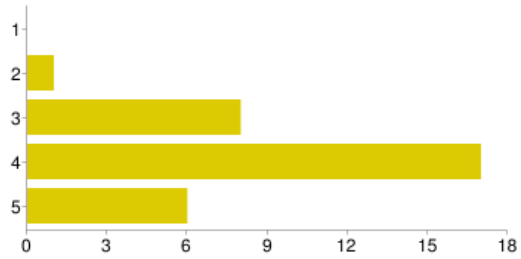
3. What do you think are the strengths of the Living Lab LOW3 concept in comparison to other educational offers

Collaborative and participatory learning environment



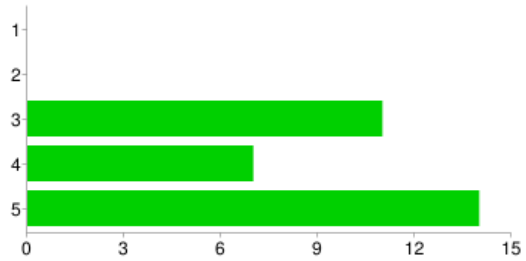
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	9	28.1%
4	16	50%
5	7	21.9%
AVERAGE EVALUATION: 3.99		

Transdisciplinary teaching and research in sustainability



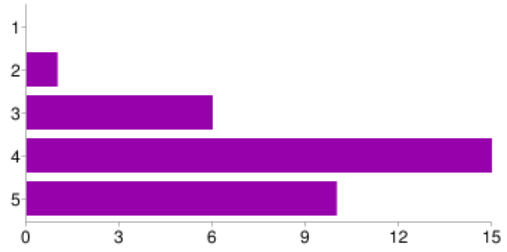
Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	8	25%
4	17	53.1%
5	6	18.8%
AVERAGE EVALUATION: 3.88		

Holistic approach to sustainable life style and energy efficiency



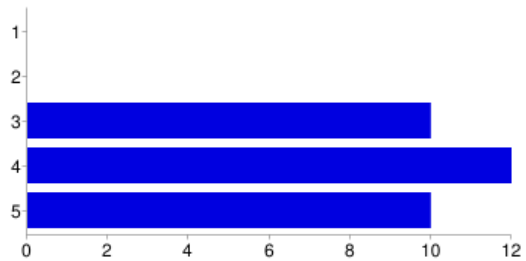
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	11	34.4%
4	7	21.9%
5	14	43.8%
AVERAGE EVALUATION: 4.09		

Experience-based and user-centred research environment (1:1 prototype)



Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	6	18.8%
4	15	46.9%
5	10	31.3%
AVERAGE EVALUATION: 4.06		

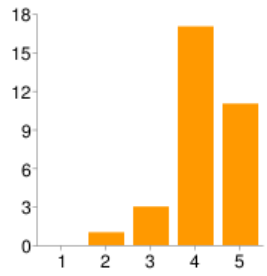
Open platform for co-creation and innovation activities



Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	10	31.3%
4	12	37.5%
5	10	31.3%
AVERAGE EVALUATION: 4.00		

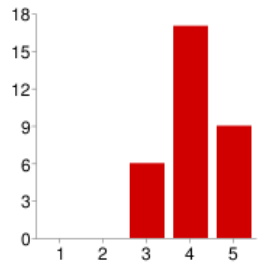
OVERALL RESULTS

4.1. Was the seminar useful for you?



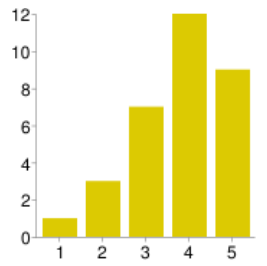
Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	3	9.4%
4	17	53.1%
5	11	34.4%
AVERAGE EVALUATION: 4.19		

4.2. Has your holistic understanding of sustainability been improved?



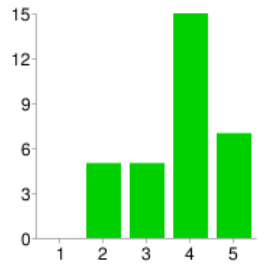
Value (1-5)	Answers	Percentage
1	0	0%
2	0	0%
3	6	18.8%
4	17	53.1%
5	9	28.1%
AVERAGE EVALUATION: 4.09		

4.3. Have you been able to generate innovative ideas?



Value (1-5)	Answers	Percentage
1	1	3.1%
2	3	9.4%
3	7	21.9%
4	12	37.5%
5	9	28.1%
AVERAGE EVALUATION: 3.78		

4.4. Could you benefit from networking with other participants?



Value (1-5)	Answers	Percentage
1	0	0%
2	5	15.6%
3	5	15.6%
4	15	46.9%
5	7	21.9%
AVERAGE EVALUATION: 3.75		

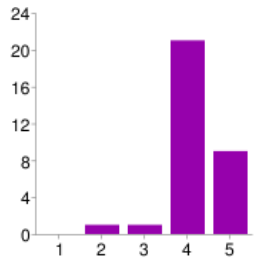
Comments about RESULTS:

- Perfect
- It was a nice visit and knowledge experience
- I really liked the results, I learned a lot about sustainable building, an area in which I didn't
- know anything

- Good
- I am very grateful for this event. In fact I am confused about the second year research direction and this event gives me some inspiration.

FINALLY...

Overall evaluation of the seminar

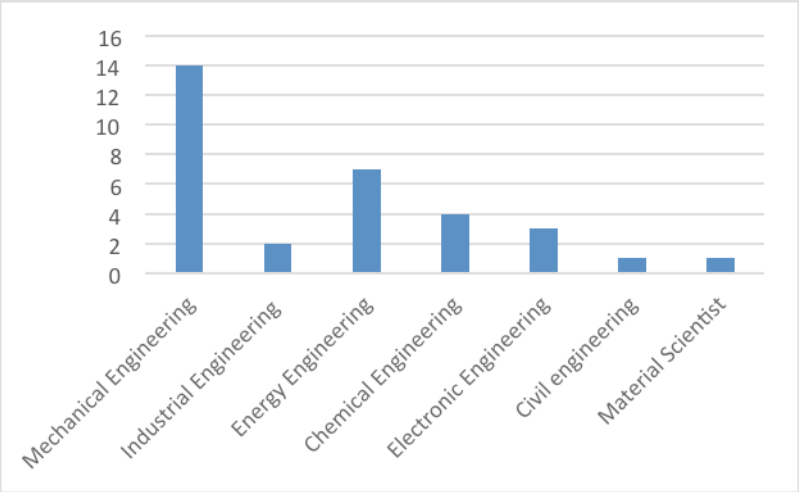


Value (1-5)	Answers	Percentage
1	0	0%
2	1	3.1%
3	1	3.1%
4	21	65.6%
5	9	28.1%
AVERAGE EVALUATION: 4.19		

Comments and recommendations for future seminars:

- The time provided for actual brainstorming and group work was to short in my opinion. It takes some time to totally understand some specific concepts and then to improve them and wrap a story around them requires some more time.
- I think this is a great seminar, I had lots of fun and learned even more
- It will be nice for us to talk with the students majoring in architecture.
- Suggest another place for lunch and replace the technical equipment :)
- Maybe I would structure the seminar within more days (if it is possible)
- Excellent moderator; very energetic, supportive, positive, knowledgeable, and passionate.

Background of participants (previous studies):



Age: Average age of participants has been 24.8 years, corresponding to a typical age of Master students between the first and second year of studies.

Appendix VI: Publications

T. Masseck, *Living Labs in Architecture: Open innovation and co-creation towards a more sustainable architecture and lifestyle,* WSB14 – World Sustainable Building Congress 2014, Barcelona, Conference Proceedings, http://hdl.handle.net/2117/26119

T. Masseck, *Teaching sustainability through living labs in architecture: the case study of the UPC-LOW3 prototype* EESD 2013 – Engineering Education for Sustainable Development, Cambridge, Conference proceedings *(*available: http://www-eesd13.eng.cam.ac.uk/proceedings)

T. Masseck, *LOW3 - Solar Decathlon Europe 2010: a living lab for solar architecture at the Campus Sant Cugat (UPC),* GUNI 13 - 5th International Barcelona Conference on Higher Education 2010. Global University Network for Higher Education, Barcelona, Conference Proceedings

T. Masseck, *Living Lab LOW3 – an innovative teaching concept for sustainable architecture at UPC-Barcelona Tech,* ISES Solar World Congress 2011, Kassel, Germany, Conference Proceedings

T. Masseck*, LOW3 – a Mediterranean Net Zero Energy Building,* ISES Solar World Congress 2011, Kassel, Germany, Conference Proceedings

T. Masseck *Solar Decathlon Europe 2010 : Towards energy efficient buildings,* book chapter (p. 298-302) 10Action, IDEA, Solar Decathlon Europe
(Available: http://www.sdeurope.org/wp-content/uploads/downloads/2011/10/SOLAR-DECATHLON-EUROPE-2010.pdf)