Development of a methodological framework for Técnico Alameda Campus as a Living Lab focused on Entrepreneurship and Energy

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I declare that this thesis is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Aos meus pais e à minha irmã por me terem proporcionado todas as condições para que pudesse tirar este curso.

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Resumo

A presente tese propôs-se a analisar um enquadramento metodológico que pudesse ajudar a desenvolver um Living Lab para promover o empreendedorismo em áreas ligadas à sustentabilidade energética. Começou-se pela análise de várias experiências neste domínio a nível internacional e apresentou-se uma proposta de criação de um Living Lab no Campus da Alameda do Instituto Superior Técnico, o *Campus as a Living Lab* (CALL). As alterações climáticas e a evolução da Indústria 4.0 representam novas responsabilidades e ferramentas, respetivamente, para o alcance de soluções.

Foi feita uma contextualização do Campus da Alameda (serviços e infraestruturas), bem como das iniciativas de sustentabilidade desenvolvidas. De seguida, apresentaram-se sugestões de organização das estruturas governativas, descreveram-se as medidas tomadas para divulgação do CALL, que passaram pela criação de um website e difusão da iniciativa. A estrutura do CALL foi caracterizada como uma plataforma composta por diversas camadas, às quais estão associadas tecnologias, serviços e dispositivos para soluções ligadas à sustentabilidade energética. Sugeriram-se mecanismos para angariar parceiros para o CALL, que passam pela colaboração entre o CALL e a Área de Transferência de Tecnologia. Finalmente, desenvolveu-se um caso prático que envolve a conversão do Pavilhão de Informática II em "Net Zero Building" através da instalação de painéis fotovoltaicos e baterias.

Em suma, foi elaborado um documento que pode ser interpretado como um guia para a implementação do conceito de Living Lab ao Campus da Alameda. É de referir que esta abordagem representa uma proposta pessoal daquilo que poderá ser o Campus como Living Lab, e que, como tal, seria interessante o desenvolvimento de outras propostas por parte de outros membros da comunidade do Técnico.

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Abstract

This thesis proposed to analyse a methodological framework to develop a Living Lab to promote entrepreneurship in areas related to energy sustainability. It started by analysing various experiences in this field at an international level, to later present a proposal for the creation of a Living Lab on the Alameda Campus of Instituto Superior Técnico, the Campus as a Living Lab (CALL). Climate change and the evolution of Industry 4.0 represent new responsibilities and tools, respectively, for achieving solutions.

The Alameda Campus was contextualized (services and infrastructures), as well as the sustainability initiatives developed there. Next, suggestions for organizing the governing structures were presented, and the measures already taken to disseminate the CALL were described, including the creation of a website and propagation of the initiative. The structure of the CALL was characterized as a multi-layer platform, which are associated to technologies, services and devices for solutions related to energy sustainability. Mechanisms were suggested to attract partners for the CALL, which involve collaboration between the CALL and the Technology Transfer Office. Finally, a case-study involving the conversion of Pavilhão de Informática II into "Net Zero Building" through the installation of photovoltaic panels and batteries was developed.

As a result, this document can be interpreted as a guide for implementing the Living Lab concept on the Alameda Campus. It should be noted that this approach represents a personal proposal of what the Campus as a Living Lab could be, and that, as such, the development of future proposals by other members of the Técnico community would be important.

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1. Introduction

1.1 Motivation

Over the last decades, the need to adapt and mitigate Climate Change gained a lot of emphasis. In the same period, the effects of global warming manifested with an increase of the surface global temperature of $0{,}82℃$ over the 20^{th}century average [1]. The greenhouse gas emissions, that play a significant role in climate change, reached in 2019 a new high record of $52{,}4\ GtCO_2e$ (without land use)[2]. These tendencies lead to an increased occurrence of extreme natural events such as wildfires, floods, droughts, rising sea levels and, water scarcity, to name a few. The existence of such events puts people and biodiversity directly at risk and affects the quality of life on earth. There is an urgent need for action to minimize the consequences of climate change, meaning that sustainable development of society must be pursued.

Sustainability

A sustainable development aspires to allow progress in a way that satisfies the needs of the present generations without compromising the capacity of the futures generations to satisfy their needs [3]. The activities and products developed by the present generation should minimize the environmental impacts associated to it, be financially viable, and somehow represent a positive contribution in the social conditions of the general population. Thus, an activity or product can be considered sustainable according to three dimensions of sustainability: ecological, economical, and sociocultural.

The ecological dimension of sustainability regards environmental impact and it aims the reduction/minimization of environmental pollution, minimize the resources consumption [5], mainly to ensure the protection of all type of resources, conservation of biological diversity and continued productivity and functioning of ecosystems [4]. Several indicators can be used to evaluate ecological sustainability, Land Use, Primary energy consumption (renewable/non-renewable), Global Warming Potential, Ozone Depletion, to name a few.

Economical sustainability can be seen from 2 different perspectives: first, the society standpoint, as the limitations that the society places on economic growth to avoid compromising the integrity of the environment to a certain degree, since policies designed to maximize capital often interfere with sustainable development priorities[4]. Secondly, economical sustainability can be seen, in the case of a building, as the costs associated with it. From construction costs, which include the costs of the land, building the infrastructures, construction supervision and, documentation, to usage costs, that involve energy and water consumption and dismantling costs, representing the costs of demolition, removal, reuse/recycling or disposal[5].

Finally, sociocultural sustainability represents the satisfaction of basic human needs and the guarantee of equity and participation [4]. Health and comfort are and important indicators, whether it is thermal comfort, a hygienic environment, and protection from hazardous substances. Accessibility is important to promote diversity and participation, manifesting either through the inclusion of people from different social and cultural backgrounds or infrastructures that guarantee easy access to people with conditioned mobility. Social responsibility is also associated with sociocultural sustainability, as any action must not only benefit the one taking action, it must represent a benefit to the whole society to be considered sustainable.

UN SDG

Some populations already suffer from climate change in a harsh way, either through food and water scarcity or the loss of a home to a natural disaster. It was estimated that there were approximately 30 million climate refugees across 135 countries in 2017 and it is estimated that this number can increase to 143 million by 2050 if no actions are taken to mitigate climate change[6].

Measures have been taken to address concerns related to climate change and pursue sustainable development across the globe. The UN established the 17 Sustainable Development Goals (SDGs), see figure 1.1, to tackle climate change, preserve oceans and forests while aiming to improve health and education, reduce inequality, and stimulate economic growth [7]. The goals were set in 2015 to be accomplished by 2030.

Figure 1.1- The UN 17 Sustainable Development Goals

The Global Warming issues faced since the last century lead the United Nations (UN) to recognize *that "climate change represents an urgent and potentially irreversible threat to human societies and the planet"* [8]. The consequences can manifest through increasing hunger and poverty, desertification, water scarcity, compromised life below water and on land, among others. The 21^{st}Conference of the Parties in Paris, 2015, culminated in the Paris Agreement, an international treaty developed with the purpose of limiting Global Warming to a maximum of 2°C, compared to pre-industrial levels [8].

In compliance with the Paris Agreement, Portugal aims to achieve carbon neutrality by 2050. This represents a global commitment to contribute actively to tackle global warming and a national commitment, as Portugal is one of the countries that will suffer the most from climate change, either by the consequences of sea level rise across all 943 km of the Portuguese Coast, wildfires, severe droughts (in the southern regions) or extreme rainfall (in the northern regions).

The need for action – Starting as a student, based in science

It is (or should be) everyone's commitment to contribute to a better world. No one is responsible for solving complex problems around the world, but everyone can make a small step in the right direction. In addition, with great power comes great responsibility, which is why universities must commit to this cause. Universities are accountable to educate tomorrow's leaders. This education is not limited to preparing the students to execute a profession. The universities shape the way that students observe and absorb information around them and influence their interaction with the world. The need for action regarding climate change requires the inclusion of values and concerns in education. The universities represent platforms where solutions to real-world problems can be developed and tested. In other words, universities can be seen as testbeds to develop products, services, and technologies that can solve problems with and for the community.

This approach leads to the concept of Living Lab, which is defined in "*A Milieu for Innovation – Defining Living Labs*" as a user-centric innovation milieu built on everyday 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 [9].

Técnico Living Lab

Universities such as Instituto Superior Técnico (IST) represent more than a school. With around 11 400 students, 850 professors, and 515 staff members, IST represents a diverse community that works to educate and research, being seen as an active and significant voice among the scientific and social community. With this dimension and impact comes the responsibility of striving for a better future, a future that is sustainable, by aiming towards the 17 SDGs. The Campus as a Living Lab is intended to be a contribution in that sense. The goal is to create a platform where ideas to make the Alameda Campus a better place can be shared and eventually developed, while simultaneously inviting all members of the Técnico community (Students, Professors, Staff, Researchers) to participate.

1.2 Objectives and research questions

This thesis intends to create a blueprint to the approach of the Campus as a Living Lab, representing a multidimensional proposal, from the type of governance that must be adopted, the activities developed for the engagement of the IST community (Professors, Students, Researchers and Staff), the strategies to be used to implement projects to improve energy-efficiency, as well as the university-industry relations. The design of the strategies to adopt is one of the thesis' objectives and its intention can be explained by answering the following questions:

- Which governance models are used in reference Universities Worldwide in order to engage Professors, students, researchers and staff, through a Living Lab approach?

  The review performed on University Living Labs and Sustainability related activities, chapter 2 "Establishing the concept of a University Living Lab - Literature Review", reveals two different governance models are used. The first one is the simple Top-down approach, while the second one is the complete Top-down and Bottom-up approach. As explained in chapter 2, governance following both types of approaches Top-down and Bottom-up is ideal for the engagement of all the community in activities related to sustainability and energy efficiency, either by the creation of new projects, research development, or implementation of responsible measures and behaviours. The actual governance model at IST, to be analysed further in chapter 3 "Status of Energy Management and Entrepreneurship activities at IST", is yet to be completed with the Bottom-up part, which will especially allow to engage students, researchers and staff in energy efficiency and sustainability-related activities.

- How to implement this approach in Técnico?

  This question represents the purpose of this thesis. There is no correct answer on how to correctly implement the CALL in Técnico as it has never been done before in Técnico. However, the literature review showed that the universities that successfully implement Living Lab type activities in their campus rely on mechanisms to engage the community. The mechanisms such as funds, courses, and grants are generally developed by the governance of the university in collaboration with the office responsible for sustainability. In Técnico, the Energy Initiative works in collaboration with the management council and the governance to develop the sustainability/energy efficiency related activities, however, the mechanisms to stimulate the engagement of the community have not been created yet. The implementation of the CALL in Técnico will require both parts of the organizational structure, the Top-down and the Bottom-up. The activities already developed correspond to the Top-down part, meaning that the structure must be completed with the tools necessary to complete the Bottom-up part, which is described in chapter 4 "Developing strategies for IST Campus as a Living Lab on Energy and Entrepreneurship: The CALL initiative", with the creation of a website dedicated to the CALL, questionnaires and invitations sent to Técnico's community members, classification of Living Labs and description of the CALL as a multi-layer platform.

- <u>How to make use of the CALL to improve university-industry relations?</u>

  The development of some of the CALL activities will involve collaboration with industry partners. There are several motivations behind these partnerships: to the industry partners, the participation in the CALL represents the opportunity to use the IST Campi as a testbed very close to a real-life scenario to test technologies and services. The partners also get to meet the students that soon will enter the labour markets, allowing the companies to target the students they want to work with and helping graduate students to find a job. To the university, the partnerships with the industry represent the opportunity to improve the campi towards climate neutrality, by having access to equipment, services, and technologies provided by the partners. Chapter 4, specifically in "4.3 Aligning ideas and financing sources - Promote industry-university relationships" addresses the possibility of partnerships with industry partners and the possibility of government support as well, and the benefits for all the involved parts.

- <u>How to develop specific projects to improve energy efficiency?</u>

  The concept of Campus as a Living Lab must include inputs from members of the community that are willing to participate in it. To be possible to develop specific projects it is necessary to create conditions that stimulate and support new projects and research around them, such as funds, courses and grants, previously referred to as "tools" in chapter 2 "Establishing the concept of a University Living Lab - Literature Review". The better is the development of the tools, the more projects ideas will come up from members of the community, which will allow to select and develop the best projects in energy efficiency. The Energy Initiative of IST in collaboration with the Management Council is developing the "Campus as a Living Lab for Energy (CALL for Energy)", as detailed in "Energy Initiative and the sustainable Campus Project", which performed a questionnaire to evaluate how the IST students are willing to engage in the CALL for Energy. The survey was sent to all the students of the Alameda Campus, resulting in approximately 30 responses with ideas of projects to improve the energy efficiency of the campus, which may indicate that the CALL for Energy may engage enough community members to come up with significant projects. The partners also represent an important aspect of the CALL for Energy, not only to provide services, technologies, and equipment but also to bring new subjects and ideas to be researched on and developed. So far, the CALL for Energy has already been approached by companies willing to partner and be a participant in the activities. Chapter 5 "Analysis of a case study" features an example of a specific project to improve energy efficiency, where the strategies presented in chapter 4 "Developing strategies for IST Campus as a Living Lab on Energy and Entrepreneurship: The CALL initiative" are applied.

- <u>Can we identify specific projects to be implemented in the approach of the Campus as a Living Lab?</u>

  The questionary sent via email to the members of Técnico's community resulted in approximately 30 ideas of Living Labs, which are listed in "Identifying and Mapping", table 4.1. There are several specific projects to be implemented, across the three identified themes: Mobility, Energy Conversion and

Sustainable Practices. Chapter 5 “Analysis of a case study” focuses on the implementation of a specific Living Lab project to be implemented in the Campus, a Net Zero Building. The intention is to adapt the building Pavilhão de Informática II into a Net Zero Building or Near Net Zero Building, at least. This implies the implementation of measures to reduce the typical consumption of the building, the application of Photovoltaic panels and batteries for energy conversion and storage.

1.3 Thesis Outline

This dissertation is organized in six chapters.

In the first chapter, a context on climate change and the need for action regarding energy sustainability are provided. This chapter also addresses the objectives of this dissertation with the responses to the research questions.

The second chapter describes the state of the art regarding University Living Labs and Energy Sustainability Activities developed around the world. A framework of each University is provided, as well as an analysis of the activities developed, to finally conclude with the approach followed by each institution, and the effect of different types of approaches on the development of Living Labs/Energy Sustainability activities.

In the third chapter the state of the art of sustainability related activities at Técnico is provided. First, contexts of the Alameda Campus as a community, its services and infrastructures are provided. Then, the activities developed by the Energy Initiative are presented. Finally, Técnico Partners Network is described.

The fourth chapter presents the actions that already took place regarding the creation of the Campus as a Living Lab (CALL), and the strategies to develop activities on energy sustainability and entrepreneurship. The design of the strategies requires a description of the CALL, from its governance to design of

The fourth chapter is divided in three parts. In the first one a model of governance for the Campus as a Living Lab (CALL) is suggested, as well as its insertion in Técnico's governance structure. The second part presents the activities developed so far with the purpose of acknowledging Técnico community about the CALL and a description of the CALL and its dimensions. The third and final section provides the plan for university-industry relationships establishment and partners engagement.

The fifth chapter presents a case study of a Living Lab regarding the transition of Pavilhão de Informática II into a Net Zero Building.

The sixth and last chapter presents the conclusions withdrawn from this dissertation, and a reflexion on the importance of future work for the development of the CALL.

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2. Establishing the concept of a University Living Lab - Literature Review

2.1 University Living Lab review

The Literature Review on University Living Lab addresses the implementation of Living Labs in Universities around the world. The search was performed with the following keywords: University Living Lab, Campus Living Lab, Sustainable Campus, Living Lab for Sustainability, Smart Energy Grids on University Campus. The search was performed on Google Scholar, Taylor & Francis Online and Wiley Online Library, which conducted to some initiatives performed on universities. Then, the websites of the Universities were visited to discover more about their intake on Campus Sustainability and Living Labs. This process led to choosing not only Campus Living Labs, but also projects for sustainability that were performed on universities (or in collaboration with universities).

The chosen universities/projects to perform the review are:

- Genoa University – Savona Campus, Energia 2020
- University of British Columbia (UBC) – Campus as a Living Lab (CLL)
- Wageningen University and Research
- Universidad Politécnica de Madrid – Alianza Shire
- Harvard University
- Massachusets Institute of Technology
- Delft University of Technology (TU Delft) – Green Village

2.1.1 Contextualization of each University

Before analysing each Living Lab or project for sustainability it is important to understand the context of the university where each project is developed. For that, a short review is made on the following categories:

- <u>Institution/Project</u>: Refers to the university where the Living Lab/Project is developed
- <u>Type of University</u>: Public or private university, and its dimension (number of students, number of schools/faculties)
- <u>Partnership Mechanisms</u>: Refers to the strategies adopted by the governance body to promote the creation of partnerships.
- <u>Budget/Funding</u>: Refers to the capital amount that the university has, where it comes from and how it is used.

To respond to each category Table 2.1 is filled for each one of the chosen universities, see “A. Appendixes - Research Questions Tables For each Institution” Tables A.1 to A.7.

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding
	Public or Private? Number of students and type of students? (Undergraduate, graduate, researchers…) Number of campus, schools, faculties?	Strategies/programs to promote relationships with partners? What are the partnerships for? (research, publicity, student engagement)	What's the budget of the university? Where does the funding comes from? How is it used?

Table 2.1- Research questions on University Living Lab

The sources of information used to gather the data about each university were the websites of each university. The characterization of the type of university has to answer simple questions that provide a context of the institution, such as, either the university is public or private, its number of students and their distribution between undergraduate and graduate, and the number of campus, schools, or faculties of each university. The third column of the table regards the partnership mechanisms, which is filled to provide a comprehension of the strategies and programs that the university develops to gather partners and what does the university has to offer to its partners. The fourth and last column of the table is filled with the budget of each university and the funding sources.

Genoa University:

Genoa University is a public university is composed of 5 Schools divided by several campus across the city and the region of Genoa. The university hosts more than 32 000 students and 1335 postgraduates. The Savona Campus was analysed due to being the place where "Energia 2020" was developed, having 2 300 students divided by 3 Schools. There was not found any information regarding partnership mechanisms either used in the Savona Campus or any other Campus of Genoa University. The project in analysis ("Energia 2020") is funded by the Ministry of the Environment, the Ministry of Education and the Liguria Regional Administration, with a budget of 8 million euros [10].

The University of British Columbia:

The University of British Columbia is a Public Research University with two campi, the Vancouver Campus and the Kelowna Campus. It has a total of 66 512 students, where 55 161 are undergraduate and 11 351 are graduates, divided by UBC's 16 faculties and 18 schools [11]. The UBC defines its partnerships by "5C's": Colleges and Universities, Corporations, Community, Cities and Countries [12]. This approach was developed to allow the UBC's partners to achieve their goals and objectives with the help of UBC's strengths, assets, and desires, resulting in 1 424 research projects with industry partners and 1 243 research contracts and agreements with government and non-profits. The UBC's annual budget typically sits around 3 billion $, with approximately 40% of it is coming from Government grants and contracts, 30% from Tuition and student fees, 15% from Sales and services, 7% from non-government grants, contracts and donations, 3% from investment income, and 3% from deferred capital contributions. UBC claims that around 672.7 million $ in research funding for 9,941 projects [11].

The Wageningen University and Research:

The Wageningen University and Research (WUR) is a Public Research University with 13 275 students, of which, 6 037 are bachelor's students, 6 939 are master's and 2 183 are Ph.D. Candidates [13]. TWUR is 1 faculty divided into 5 departments, Agrotechnology and Food Sciences, Animal Sciences, Environmental Sciences, Plant Sciences, and Social Sciences. To promote partnerships the WUR has the "Call for Partners", an initiative that pursues cooperation with other organizations for research in several areas [14]. The projects available for partnerships are presented on the website of the University and are open to businesses, civic organizations, or companies. The total income of the WUR for the last 3 years typically varies from 362 million € to 385 million €, where approximately 55% comes from government funding, 11% from the bilateral market, 10% from tuition fees, 9% from research funding and targeted subsidies, 5% from co-funding and matching market revenue, and 10% from other sources [15].

The Universidad Politécnica de Madrid:

The Universidad Politécnica de Madrid, UPM, is a Public University englobing 4 campus, 18 Schools/Faculties and 17 Research and Development Centres. It has approximately 35 700 students in bachelor and masters' programs and 1 900 doctoral students. There are as well 200 research groups and 71 Industry-University Endowed Chairs. The Industry-University Chairs are a mean to establish a partnership between companies/institutions and the University in order to carry out education, research, or knowledge transfer activities in an area of common interest. Two types of units have been established: Industry-University "Chair and Aulas". The differences between the two are that the "Chairs" require their own facilities while the "Aulas" can use the facilities of the school. The Chairs and the Aulas imply a minimum financial contribution of 30 000 €/yr and 10 000 €/yr respectively [16]. Data from 2019 indicates a Total Budget of 320,8 million €, with 91,5 million € from tuition and fees, 213,5 million € from public financing, 4,05 million € from private financing and 11,6 million € from international funding. The research is sponsored with 19,1 million € from public national funding and 3,7 million € from contracts with private industry [17].

Harvard University:

Harvard University is a Private Research University with 12 Graduate and Professional Schools and one Institute. Data from the academic year of 2018-2019 indicated that the university had 31 566 students, with 9 950 in undergraduate courses and 21 616 in graduate courses [18]. Each School of the University makes partnerships with entities regarding its area of research/teaching. The Office of Technology Development works to connect innovators with industry. The partnerships are made to benefit each part. To the faculty and Inventor, it is possible to advance the research, protect intellectual property and execute a business development strategy.

To the Industry and Inventor, the benefits are to gain access to Harvard's innovators and innovations, license technologies, and catalyse start-ups [19]. The financial overview indicates for 2020 an Operating Revenue of 5 400 million € with the following sources: 37% endowments, 17% Education/tuition, 17% Research, 9% Gifts, 20% Other [20].

The Massachusetts Institute of Technology:

The Massachusetts Institute of Technology, MIT, is a Private Research University. It is divided in 5 Schools and 1 college across an urban campus. There are 11 520 students at the MIT, 4 530 of them being undergraduate and 6 990 graduate [21]. Currently, over 700 companies are working with faculty and students on projects of mutual interest. MIT Corporate Relations aids and directs companies interested in multidisciplinary involvement with the Institute, with 2 programs, the Industrial Liaison Program and MIT Start-up Exchange. The Industrial Liaison Program is instrumental in providing connections to MIT faculty, departments, labs, and centres. It serves companies across the globe and is organized both geographically and by industry, while MIT Start-up Exchange actively promotes collaboration and partnerships between MIT-connected start-ups and the industry. Qualified start-ups are those founded and/or led by MIT faculty, staff, or alumni, or are based on MIT-licensed technology [22]. For the year of 2019, the Total Operating revenues were 3 932 million $ and the sources were: Research – Lincoln Laboratory 27%, Investment Return 22%, Research – Campus 19%, Gifts 10%, Tuition 10%, Other operation 8%, Auxiliary enterprises 3%, and Research – Singapore MIT alliance 1% [23].

Delft University of Technology:

TU Delft is a Public University composed of 8 faculties, with a total of 26 480 students. There are 13 806 bachelor's students, 12 435 master's students, and 2 921 Ph.D. students[24]. The research projects can be supported by partners and for this purpose the projects are listed on TU Delft's website to be analysed by eventual partners. The partnerships can be made with associations, industrial partners, and academic partners. There are as well initiatives to stimulate support from partners, "Business Friend", "Good Friend" and "Your Named Fund". The "Business Friend" requires from the partner a minimum donation of 2 500€/yr for 3 years to allow him to be part of a network of businesses that are closely involved with TU Delft. This guarantees the benefits of attending major events at TU Delft, subscribe the "Friends Newsletter" and publicity [25]. The "Good Friend" requires from the partner a minimum donation of 500€/yr for 5 years (or 1 single donation of 2 500€) to be part of a network of committed alumni and other associates of TU Delft. This guarantees the benefits of attending major events at TU Delft, attending a masterclass (twice a year), subscribing the digital "Friends Newsletter", and being credited in the Delft University Fund annual report and on the Good Friends webpage [26]. Through "Your Named Fund" a named fund can be established by donating via notarial deed or by including the Delft University Fund in an investment of at least € 50,000 in a single instalment or five annual instalments. The donor can determine what is done with its assets and discuss his wishes with TU Delft in detail [27]. TU Delft Annual Report 2019 presents a total income of 762 million € with the following sources: 439 million € from

Government and other contributions, 216 million € from Projects with third parties, 73 million € from Tuition and examination fees, and 34 million € from other sources [28].

All the universities present programs for partnership, with the possibility of associating mostly with academic partners, corporations/industry, and governmental and non-governmental associations. All the universities accept donations as well, presenting programs with offers in exchange.

As expected, for the public universities in analysis, UBC, WUR, UPM, and TU Delft, the main sources of financing are Government/Public funding, tuition fees, and research/services performed.

The private universities, Harvard University and MIT, have shown that their bigger sources of financing are endowments, research, and tuition fees.

From the analysis above it is possible to calculate the budget per student of each university, table 2.2, except for Genoa University, which financial information was not found.

Institution	Budget per student
UBC - public	≈ 45 000$
WUR - public	≈ 28 000€
UPMadrid - public	≈ 9 000€
Harvard University - private	≈ 171 000$
MIT - private	≈ 341 000$
TU Delft - public	≈ 29 000€

Table 2.2- Budget per student of each Institution

The purpose of the analysis of the budget of each university is to understand how a higher budget or budget per student will be traduced in living labs or projects/initiatives for sustainability.

2.1.2 Analysis of Living Labs/Sustainability Projects in Universities

The analysis of each project, living lab or initiative is made according to the following topics:

- Definition of Living Lab: refers to the definition adopted in the different case studies analysed.

- Governance: refers to who oversees what. Understand how the working groups are organized and what are their functions.

- Objectives: refers to the tangible goals that are set to help tracking the evolution of each initiative.

- Strategy: refers to the path that is adopted to fulfil the purpose of the project, from gathering the partners to the methods used to achieve the objectives.

- Partnerships: refers to the type of partners and their contribution to each project.

- Outreach/Achievements: refers to the impacts and accomplishments of the initiative.

- Projects: refers to the projects developed within the initiative.

To describe the projects according to each topic the question must be answered to fill a table like Table 2.3 for each university, see "A. Appendixes - Living Lab/Project characterization Tables for each institution" Tables A.8 to A.14.

Institution/Project	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/ Achievements	Projects
	How does the governance define LL?	Who oversees what? How is the governing group organized?	What are the goals to be achieved with the creation of this activity?	What is the developed strategy to achieve the goals?	Who are the partners of the project? How will they help?	What goals have already been achieved? Other achievements than the goals?	Which projects have been developed?

Table 2.3- Categories and questions for Living Lab analysis

Genoa University:

"Energia 2020" a pilot experiment of a Smart Sustainable City was developed in Savona Campus, Genoa University. It is managed by the University Service Centre (entity responsible for the activities in Savona Campus). The research activities are performed by the Power System Research team of the University of Genoa. It is intended to be an "innovative and high performance building to meet goals of zero carbon emissions, energy and water efficiency and building automation" [29]. This project has the objectives of representing the first "Smart City" urban infrastructure, conducting research and innovation on smart energy building, energy management systems and microgrids. The exchange of information, ideas, and best practices for achieving sustainable campus operations and integrating sustainability in research and teaching is also another objective for this project. The project is the result of a partnership between the Italian Ministry for the Environment and protection of Land and Sea, the Italian Ministry of Education, University and Research, and the Liguria Region, with contributions of 2,7 million €, 2,4 million € and 1,5 million € respectively. "Energia 2020" has so far resulted in a participation in ISCN's "Sustainable Development: Educating with Purpose" [30] and in a Campus that is used as a "test-bed" of state-of-the-art technologies for the City of the Future (digital City hyper-connected, City secure, health & wellness for the Citizens), featuring a U-Gym and a Living Lab to test electrical appliances. The approach of Smart City is applied through different projects developed simultaneously, the Smart Energy Building (SEB), the Smart Polygeneration Microgrid (SPM), Energy Efficiency Measures (EEM), and a Smart City Demo.

The Smart Energy Building is connected to the Smart Polygeneration Microgrid which is a smart microgrid responsible for providing electrical and thermal energy. The SPM features technologies such as micro combined Heat and Power gas turbines, natural gas boilers, photovoltaic fields, Concentrating Solar Systems, water/lithium bromide absorption chiller, electrical storage systems, battery electric vehicle charging stations [31]. The SEB features a geothermal heat pump (45 kWth), a traditional heat pump, a photovoltaic field, thermal solar collectors, and a rainwater collection system [31]. Efficient LED lighting systems, efficient thermal insulation materials and ventilated facades are also used in the SEB. The building hosts the U-GYM, a gym with equipment that generates electricity while being used to work out, and a domotic laboratory to test electrical appliances (as a Living Lab). The SPM is equipped with an Energy Management System (EMS). It is composed of hardware and software tools that operate to minimize the costs of building operations and CO_2 emissions. The EMS schedules the operation of fossil-fuelled generators and electrical storage systems [31], allowing the management between photovoltaic production and the power stored, as an example. The Energy Efficiency Measures are implemented to upgrade and monitor the energy efficiency of the Campus buildings. Finally, the Smart City Demo Campus is the transformation of the Campus into Smart Urban District of the Future, installing new technologies in information and communication technology, energy, and environment sectors in order to show a real implementation of the Smart City concept to population and external stakeholders [32].

The University of British Columbia:

The University of British Columbia (UBC) defines Living Labs as "physical spaces and human systems in which we design, test, study, and learn from social and technical innovations in real time and real world contexts. They support collaborative experimentation, piloting of innovations, critical assessment of results, and exchange of knowledge" [33]. The activities of the Campus as a Living Lab (CLL) are managed by the Sustainability Initiative that includes various committees and working groups, involving dozens of individuals (academics, board representative members, student advisory members, various managerial staff) with direct reporting between them. The objectives of the initiative are to respond to challenges as climate emergency, ecosystem destruction, global urban migration, pandemics, and economic change by integrating academic research and teaching with campus planning, infrastructure, operations, and community development. For this the UBC plans to use the campuses as a testbed for the potential commercialization of products that can help with campus sustainability. Tangible goals were set to track the progress towards sustainability, which include a 33% reduction of the 2007 levels by 2015 and a 100% reduction of the 2007 levels by 2050 [34]. The CLL develops projects that will help to achieve the goal and can occur either by solicited proposal or unsolicited proposal. The solicited proposal projects are issued by the governance with a defined action plan and funding, while the unsolicited proposal projects start with the submission of the proposal, which later is reviewed by the different working groups and committees to evaluate it and eventually fund it. As it will be described further, the solicited proposal projects correspond to a top-down type approach, while the unsolicited proposal projects follow a Bottom-up type of approach. The UBC CLL partners with Companies and NGOs as there is interest in working with industrial and community partners. For that, UBC issued a request for information to develop strategic partnerships with the industry in 2011, resulting in an increasing number of companies approaching UBC to collaborate. Three different projects were developed, resulting in to actively tackle the emissions. The first is The Centre for Interactive Research on Sustainability (CIRS), consisting of a building that can be used as a LL and a "net-positive energy producer and net-zero carbon building". It features a Building Management System (BMS), allowing the monitorization off occupancy, CO_2 levels, VOC, room temperatures, energy meters, HVAC related data, windows status, solar PV, and transmitters and water reclamation and irrigation systems, resulting in a living lab with ongoing performance monitoring and activities to further improve performance. The Academic District Energy System is a project to convert the heating system of 131 buildings across the campus from steam to hot water [34]. Aging infrastructures, natural gas prices increasing, new carbon taxes were some of the motivations for this change, allowing to reduce GHG emissions by 22% and save annually 5.5 million Canadian Dollars. The project had a cost of 88 million Canadian Dollars. The third project is the Bioenergy Research and Demonstration Facility, which goal is the reduction of imported power on campus by using a renewable source for fuel. This project reduces UBC's GHG emissions by 9000 tonnes per year. *Save et al.* [34] also proposes a structure of a Business Process Model (BPM) that can be adapted to various projects to evaluate and structure tasks. The UBC CLL is featured on ISCN's "Sustainable Development: Educating with Purpose".

The Wageningen University and Research:

Wageningen University and Research (WUR) defines Living Labs as "good ways to test, create and develop metropolitan solutions with impact. It makes a connection between fundamental research and the step to a society-wide implementation" [35]. WUR implemented a Living Lab approach to make "students of the master's Metropolitan Analysis, Design and Engineering (MSc MADE) work on real-life cases within the city of Amsterdam" [35]. This initiative allows the students to work with stakeholders and Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute) to find solutions for real-life urban challenges. AMS Institute states that "Living Labs are an attractive way to test, create and develop metropolitan solutions that will be adopted more smoothly and swiftly by all stakeholders involved" [36], having already developed several Living Labs. Each Living lab is then governed by MSc MADE students. The MSc MADE was created to develop research around 6 urban challenges: Smart Urban Mobility, Urban Energy, Climate Resilient Cities, Metropolitan Food Systems, Responsible Urban Digitization, Circularity in Urban Regions. The first academic year of the degree "consists of courses such as Metropolitan Challenges, Data and Entrepreneurship. These will prepare you for the Living Lab in the second year. The Living Lab approach will enable you to work on real-life cases within the city of Amsterdam"[37]. The MSc MADE results in MADE students, collaborating with AMS Institute and other entities, leading to the creation of new Living Labs every year, such as Living lab DGTL- Illuminating NDSM, WASCOM - urban waste to urban material, and Concretely Circular, to name a few [38]. Living lab DGTL - Illuminating NDSM consists in the development of movable light objects that can be used as atmospheric lighting during DGTL festival and for street illumination in a dark area of the city where many streetlights are broken. WASCOM - urban waste to urban material regards the development of a product with an urban application from a new material (WASCOM) made of wastewater flows from the city, resulting in a flower planter. Finally, Concretely Circular seeks to change the Concrete is one of the largest waste streams and most of its waste in the Netherlands is "downcycled" and used as a foundation for roads and infrastructure. This project aims to recycle concrete to produce products with higher value, upgrading the value of the concrete in the value chain.

The Universidad Politécnica de Madrid:

The Technical University of Madrid participated in a partnership, "Alianza Shire", to provide energy access to refugees and displaced people. Despite not considering itself as a living lab, this initiative features some characteristics of living labs, as it is the application of technology to solve a real-world situation, with the support of stakeholders and involvement of the local community. It is governed by three management bodies [39]: the Steering Committee that composed of managers from each partner entity, working at the strategic level of the partnerships and is in guidance of the partnership and its initiatives and projects, the Technical Team, composed of experts on energy from each partner entity with the purpose of providing support to other groups, and a Communication Committee, composed by one member of each partner with the function of managing the Partnership Internal communication, develop communication protocols and planning internal and external communication, responsible for the organization of information to allow efficient knowledge management. The

Partnerships are established to plan, fund, and perform the activities, where the Universidad Politécnica de Madrid plays the role of facilitator and promoter, being responsible for the design and the management of a space for collaboration and to monitor the working process, the Spanish Agency for International Development Cooperation and UN High Commissioner for Refugees are organizations that ensure institutional support and a wider knowledge of the humanitarian context, the Norwegian Refugee Council is an NGO operating with the purpose of promoting and safeguarding the rights of displaced people, and ACCIONA Microenergia Foundation, Iberdrola, Philips are the 3 leading private companies in the energy sector and provide technical knowledge on models for energy service provision, innovation, renewable energy, lighting, and business model. This initiative not only covers the improvement and extension of the electricity grid, installation of LED luminaries for street lighting, it has a training and participation principle as well [30] . The goal is to train refugees from the camp to be able to do the maintenance of the installations. It represents a step towards sustainability, especially regarding SDG 4 – Quality Education, SDG 7 – Affordable and clean energy, and SDG 17 – Partnerships for goals. The training of the refugees as technicians not only guarantees that there is skilled labour to perform the maintenance, but also represents a skill that can help the refugees with employment opportunities in the future. As a result, "Alianza Shire" improved life and security conditions in the campus, and also saved the production of 1500 tonnes of firewood and 2000 tons of of CO_2 emissions per year, representing an annual save of 30 000€ in diesel consumption [30]. The Project had a participation in ISCN Sustainable Development Handbook [30].

Harvard University:

At Harvard University, the Office for Sustainability (OFS) is responsible for the activities to promote a sustainable Campus. Neither the University nor the OFS identifies the initiatives as Living Labs. The OFS manages the activities related to sustainability in 5 topics: Emissions and Energy, Campus Operation, Nature and Ecosystem, Health and Well-Being, and Culture and Learning. The operations related to sustainability are developed with the goals of reducing GHG emissions, waste, and water use, and maintaining at least 75% of organic landscape on Campus. The plan to execute the activities consists of six steps. In the first place, the Campus Services and Central Administration start by Benchmarking Working Groups to provide baseline reports on current efforts and drafted goals, strategies, and opportunities for improvement. Next, Faculty, Student, and School are engaged to provide insights and comments on the draft goals, and later the OFS Drafts Plan with goals, standards and commitments all based on student, faculty, and staff feedback. Then, the Review Committee, composed of senior-level School Operation leaders, Central Administration departments, and students, assesses the draft plan to identify implementation barriers or School-specific concerns and thus make specific recommendations on the proposed goals. After that, all communities meet with facility leaders, Green Teams, Strategic Procurement, Human Resources, and other stakeholders for discussion of the plan. Finally, the School Review and Sign Off is made by individual meetings with each School and Central Administration department leadership to review and sign off the final draft of the Plan [40]. The partnerships are made with higher education institutions, government, non-profit organizations, and private businesses, such as Boston Green Ribbon Commission, Cambridge Community Compact, EcoAmerica MomentUS Initiative and International Sustainable

Campus Network (ISCN) [41]. Harvard University has developed some initiatives to develop solutions towards a more sustainable campus. The Campus Sustainability Innovation Fund is a $700,000 fund to support student research projects that tackle challenges faced directly on campus or in the community and lead to the application of new sustainability strategies [42]. The Climate Solutions Living Lab Course and Research is a three-year, multi-disciplinary course and research project led and designed by Harvard faculty to study and implement practical solutions for reducing greenhouse gas emissions at Harvard, throughout the United States, and abroad. Finally, there are Student Grants to provide seed funding for student projects that contribute to Harvard's commitment to climate and health, and which help create a more sustainable campus community [40]. The main achievements of the activities developed at Harvard University are the creation of Harvard University's first Sustainability Plan, "Green Harvard" an online Dashboard to track progress related to sustainability, and an active participation in ISCN's sustainability activities [43].

The Massachusetts Institute of Technology:

The Massachusetts Institute of Technology (MIT) defines living labs as "rigorous campus-based research with operational, academic partners, sustainable data collection/analysis, formal and informal learning activities and measurable outcomes" [44]. The MIT Office of Sustainability (MITOS) is responsible for the development of a living lab and sustainability-related activities in the campus, creating projects in 5 areas [45]: Zero-Carbon Campus - activities regarding climate, buildings, energy and mobility , Climate Resilience - activities regarding planning, climate risks, education and resilient ecosystems, Material Life-Cycle - activities regarding procurement, waste, and re-use, Healthy People - activities regarding food and environmental justice, and Thriving Networks - designing the partnerships to advance in sustainability. The MITOS is developing the Living Lab with the purpose of solving global sustainability issues at a local level. The strategy for living lab development consists of processes that occur simultaneously [44], starting with a Research Process, where there is linear and non-linear sequencing of research questions, literature review, design methodology, data collection/analysis. Next, it is the Ideation Process, to draw non-linear sequences such as intake/define, collaborate, digest, prototype, connect/reconnect, test/outcomes. Then, the Filter Process includes a non-linear process by which strategic decisions about the prioritization of new work, or about the next steps of existing work. Finally, the Teaming Process occurs with team launch, team build and team re-launch. Partnerships are developed in three categories [46]: Campus partnerships – between members of the MIT community (scientists, researchers, staff, students), City partnerships – developed with the Cities of Cambridge and Boston, and Global partnerships – with entities around the world. The partnerships are developed to achieve solutions on campus, at a local and global level, respectively, with the purpose of sharing knowledge and fund. The MITOS developed a course, "Solving for Carbon Neutrality", [47] which engages students to develop solutions to achieve Carbon Neutrality. There is an "Incubator Fund" [48] that was created to stimulate the community of students and researchers to work on solutions towards sustainability., using the campus as a testbed for research. Certifications of sustainability have also been created, the Sustainable Workplace Certification [49] and the Sustainable Event Certification [50], that are programs designed to empower the staff, students and workers to take leadership roles in implementing strategies and practices to make their workplace healthier and to reduce the environmental impact of events in campus, respectively. The MIT is also a participant in ISCN' sustainability activities [30].

Delft University of Technology:

The Delft University of Technology (TU Delft) in collaboration with Stichting Green Village rehabilitated a building to create The Green Village. The management is in charge of a team of nine members, with the responsibility of managing the project, terrain activity coordination, and marketing and communication. The goal of The Green Village is to allow knowledge and educational institutions, entrepreneurs, government bodies and civilians to research, experiment, validate and demonstrate innovations for a sustainable future [51]. The activities developed are divided into 3 different themes [52]: Sustainable Building and Renovation, Future Energy System, and Climate Adaptive City. Sustainable Building and Renovation focuses on new and existing houses that require sustainable (circular) building/renovating in order to prepare for the future, meaning energy efficient, climate adaptive and by applying reusable raw material [53]. The Future Energy System [54] works on the transition to sustainable energy, meaning drastic changes in the energy system. For that, new energy carriers, such as heat and hydrogen must be used, requiring numerous innovations for storage and management. Finally, Climate Adaptive City [55] works on developing solutions adapted to the increasingly extreme weather, to make the city fit either for long dry periods and for heavy rainfall. It has the support of the European Regional Development Fund, Provincie Zuid-Holland, the municipality of Delft, Alliander, Gasterra, among others [56]. An example of the developed projects are "Rainroad" – a solution to be used under the pavement to provide cooling during hot days and to avoid floods during extreme rainfall [57], "Buffer Pavement" – a project to produce concrete tiles that emit between 80 and 90% less CO_2 during production than the traditional ones and present a higher capacity to buffer the water and avoid floods [58].

2.1 Review on University Living Labs governance structure

The initiatives are generally developed by the Sustainability Department of each Institution. In the case of the Living Labs, more power is given to the working group, as in the Projects, the working group generally follows a plan from the administration. The Living Lab normally implies the submission of a proposal to the administration of the institution and/or partners to finance the activities, as, in the case of the Projects, the fund is made available by the administration/partners for the activities to take place.

The analysis of the activities developed on the universities above described allows concluding that the projects can be divided into 2 parts: Top-down and Bottom-up.

The Top-down part corresponds to the development of plans to develop projects related to sustainability. The decision comes from the governance of the university or the committee responsible for sustainability. The plan is developed and the funding for it is normally secured, either from the university or from a partner. Later, the community is engaged in the activities and finally, the project or measures is/are implemented. This is applied in all the universities analysed and it can be seen as the "first half" of the creation of a Living Lab, and its structure is expressed in Figure 2.1.

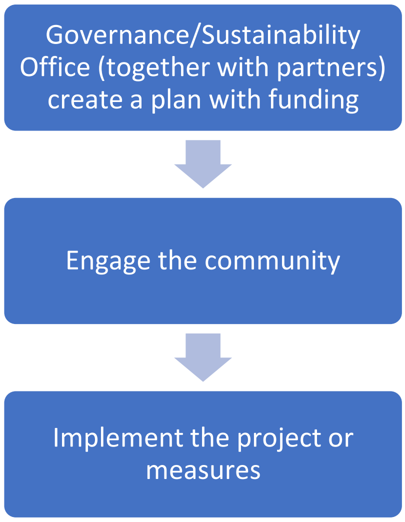

Figure 2.1- Top-Down governance structure

The Bottom-up part corresponds to the development of plans/projects by students or researchers, with the motivation to create or develop sustainable solutions. The plan is developed before raising funds to execute it, so it must be presented to the higher entities (governance, office of sustainability) for approval and eventual funding. The funding may also come from partners. This type of approach comes after the top-down approach because it requires the necessary conditions to support the new ideas. Not all the universities analysed allow this type of approach, see structure in Figure 2.2.

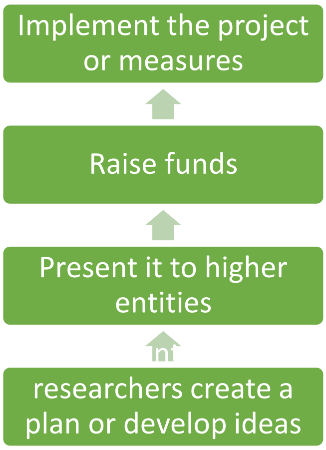

Figure 2.2- Bottom-Up governance structure

The ideal situation for the implementation of campus Living Labs is the one that allows the existence of projects from a bottom-up approach, meaning that the concept of Campus as a Living Lab is successfully applied. That requires a solid "first half", the top-down part, to develop measures that will stimulate the "second half", bottom-up part. This stimulation comes in form measures, such as Funds for projects, integration of sustainability and living labs in courses, creation of student grants, and incentive research, which can be seen as "tools" to build the living lab activities. As shown in Figure 2.3, the stimulative measures are represented in the arrow that connects the Top-down part to the Bottom-up part.

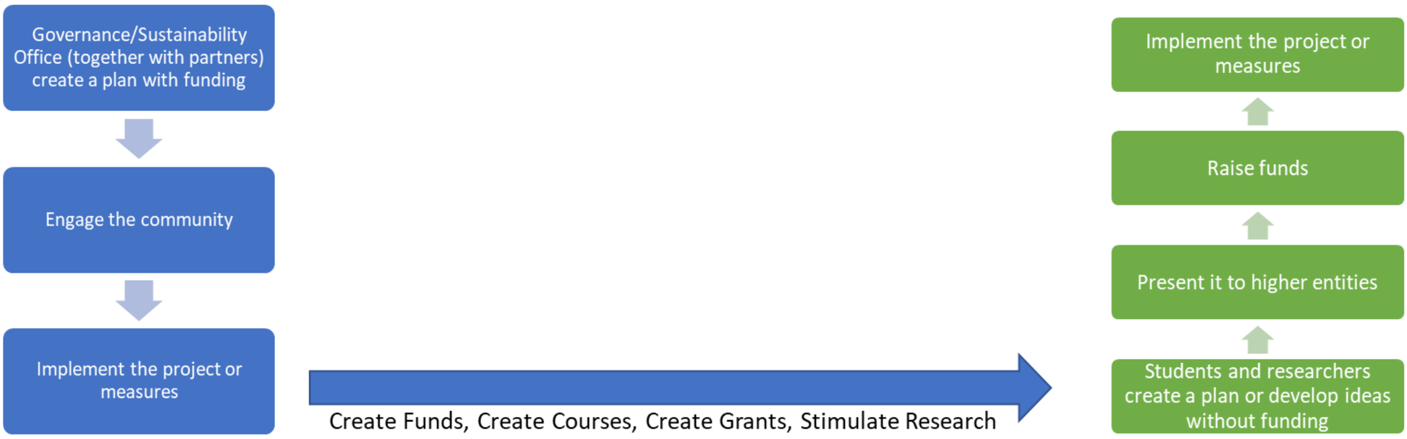

Figure 2.3- Articulation between Top-Down and Bottom-Up approaches

Genoa University’s “Energia 2020” is a project that only includes the Top-down part as the project was developed by the governance of the university with the support of the partners but once developed, it appears to not include the conditions to stimulate the creation and development of projects from a bottom-up approach.

The University of British Columbia developed the Campus as a Living Lab under the governance of the Sustainability Initiative. Later, several committees were created to develop activities related to Living Labs and there is a possibility to submit “unsolicited proposals” for activities that fit in the bottom-up approach.

Wageningen University and Research created MSc MADE in collaboration with AMS Institute and TU Delft to involve the students in sustainability related solutions. The MSc MADE represents the connection between the top-down part of the initiative (developed by WUR and the partners) and the bottom-up part. This course provides the students with the tools to develop living labs.

Universidad Politécnica de Madrid developed “Alianza Shire” in collaboration with partners. The project was developed to provide energy access to refugees and displaced people. This does not involve the creation of conditions for the university community to develop other living labs or sustainability projects, thus it represents only the top-down approach.

At Harvard University the office for sustainability is responsible for the management of activities related to sustainability, fulfilling the top-down part. In addition, the university also created an innovation fund, a living lab for climate solution course, and a program of student grants, which are initiatives that provide the students the necessary conditions to develop living labs or other sustainability related projects. Thus, Harvard University also stimulates the bottom-up approach.

At the MIT, the MIT Office for Sustainability (MITOS) is responsible for the Living Lab and sustainable development. The MITOS develops the activities promoting 5 different initiatives, which correspond to the top-down part of the plan. The MIT also created a course that engages students in developing sustainable solutions, and a fund to enable MIT community members to use the campus as a testbed. These tools represent the possibility for bottom-up projects to be created in campus.

TU Delft rehabilitated a part of the campus to create The Green Village, which represents a top-down initiative. At The Green Village, students and researchers can make use of the facilities to develop research and experiments, providing the possibility for bottom-up projects to raise.

The Table 2.4 summarizes the approach/approaches followed by each university.

Institution/Project	Top-down	Bottom-up
“Energia 2020” - Genoa University	yes	no
University of British Columbia (UBC) – Campus as a Living Lab (CLL)	yes	yes
Wageningen University and Research	yes	yes
Universidad Politécnica de Madrid – Alianza Shire	yes	no
Harvard University	yes	yes
MIT	yes	yes
The Green Village – TU Delft	yes	yes

Table 2.4- Type of approach adopted in each institution

3. Status of Energy Management and Entrepreneurship activities at IST

3.1Context

IST is composed of 3 different campi: Alameda Campus, located in centre of Lisbon with a built area of 110.000 square meters, Taguspark Campus, located in Oeiras with a covered area of 30.000 square meters, and the Centro Tecnológico e Nuclear campus, located in Loures, with 20.000 square meters of covered area [59].

IST is the biggest Engineering, Architecture and Technology School in Portugal, with a total of 11 339 students, 5 776 bachelor's students, 4 459 master's students, and 1 104 Ph.D. students, data from May 2021 [60]. IST offers 19 Bachelor's Programmes, 32 Master's Programmes, and 33 Ph.D. Programmes. There are 885 Professors and Researchers and 546 Staff Members. The ratio of Professor for Students is 1:15.

The CALL for Energy is to be implemented at Técnico's Alameda Campus, located in the centre of Lisbon. This campus is composed by 26 buildings, with a covered area of 110 000 square meters and a total campus area of 95 000 square meters [59]. The buildings are used for administrative activities, teaching, investigation and development, and support activities, such as restaurants, bars, and canteens. The area of the campus also includes outdoor spaces and parking places. The layout of the Alameda Campus is represented in figure 3.1.

Figure 3.1- Map of Técnico's Alameda Campus

The Alameda Campus was built between 1927 and 1936, under direction of Duarte Pacheco, and it included 5 buildings: Pavilhão Central, Pavilhão de Máquinas, Pavilhão de Eletricidade, Pavilhão de Minas and Pavilhão de Química. At the time it was inaugurated, the Alameda Campus was the first autonomous campus in Portugal [61]. The growth of the IST and its importance in research required the construction of new buildings. In the 90's, Pavilhão de Civil, Pavilhão de Informática, Complexo Interdisciplinar, Pavilhão de Matemática e Física, and Torre Norte were built. Finally, between 2000 and 2003, Torre Sul, Pavilhão de Mecânica III, and Pavilhão de Acção Social were concluded.

Actually, the Alameda Campus hosts 4 736 bachelor's students, 3 934 master's students, and 1 104 Ph.D. students, resulting in a total of 9 774 students [62].

The activities that occur at the Alameda Campus daily go beyond the lectures and research, the infrastructures host conferences, seminars, and colloquiums, contributing to the scientific purpose and multidisciplinary of the IST.

The IST's Statistics and Prospective Unite emitted in May 2021 the "Facts and Numbers" of the IST [60], declaring an annual budget of 107 million €, of which 51% are self-funded. Despite being emitted in May 2021, the budget presented in this document was updated in September 2017. This results in an annual budget per student of approximately 9 500€. When comparing this value with the values of budget per student of other universities, shown in Table 2.2- Budget per student of each Institution, it is evident that the IST's budget is one of the smallest. The only University presenting a smaller budget per student is the UP Madrid, with approximately 9 000€/student.

The analysis of the Type of Approach followed at IST reveals that there is only a Top-Down approach, according to the classification presented in chapter 2 "Establishing the concept of a University Living Lab - Literature Review". The activities related to sustainability developed in the Campus are managed by the Governing Board. There are no funds, courses, or grants created specifically to stimulate and engage the community in establishing new activities, despite the existence of sustainability related activities that include students and researchers, as the "Campus Sustentável", managed by the Energy Initiative and to be addressed in 3.2 Energy Initiative and the sustainable Campus Project. The information presented in Table 2.4 reveals that, similarly to IST, the University of Genoa and The Technical University of Madrid do not follow a Bottom-Up type of approach. It is possible to conclude that the annual budget available to each university has a direct influence on the type of approaches followed by it, as a bigger budget can be traduced in the creation of measures to stimulate the bottom-up approach, and in opposition, a smaller budget limits the possibilities of attributing funds and creating courses and grants.

3.2 Energy Initiative and the sustainable Campus Project

Sustainability in IST is addressed by a working group of IST funded in 2011, named "*Técnico - Campus Sustentável*" ("Sustainable Campus"). The team dedicates to optimizing the use of resources in Técnico. The project includes a team working to implement improvements in the campi's everyday life. This team also has the function of being a link between everyone that is involved, students, professors, staff, and collaborators [63].

The main achievements manifested through measures in energy consumption, water-use, sustainable mobility, and residues treatment and recycling [64].

3.2.1 Electrical energy consumption:

The sustainability project started by performing energy audits in IST campi.

To reduce the energy consumption of the Alameda Campus, measures were applied:

- Sensibilization of building managers, maintenance workers and other staff members for the adoption of better energy management practices.
- Introduction of low activity periods and stipulation of specific rules to optimize energy and water consumption in the same periods.
- Centralization of servers and data centres on appropriate accommodations
- Inspection of the HVAC systems of the 3 campi
- Installation of electricity meters for monitorization of the energy consumptions of each building of the Alameda Campus.

The introduction of electricity meters allowed the development of "EnergIST", a platform were the monitored energy consumptions are published on a platform that is available to Técnico' community.

This intervention resulted in significant savings in energy consumption, see Figure 3.4.

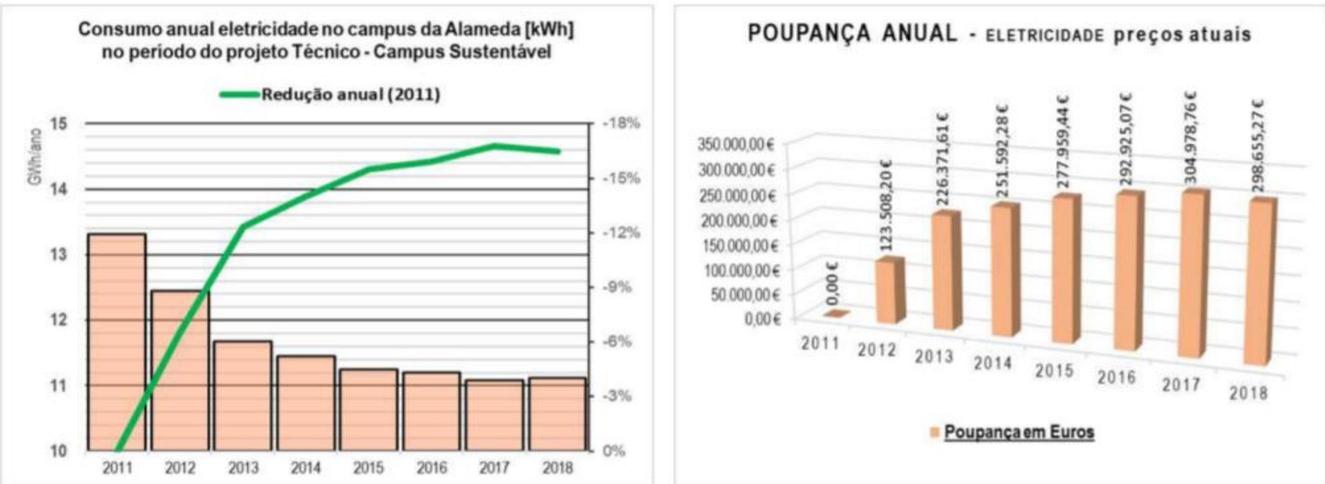

Figure 3.2- Results of Técnico Sustentável in energy consumption and annual savings, from [64]

The data analysis reveals a reduction of electrical energy consumption of 16% between 2011 and 2018. The adoptions of the measures described above avoided the consumption of 13 GWh of electricity. This is equivalent to 6 102 tCO_2eq of GHG emissions avoided, according to Campus Sustentável's workgroup. Financially, it traduced in accumulated savings between 2011 and 2018 of over 1,7M€. It is important to mention that during the same period the price of electricity tariffs increased approximately 20% [64].

3.2.2 Water-use:

Until 2012 there were no strategies to measure and control water consumption. Before Técnico Sustentável, the water consumption at Alameda Campus was approximately 140 000 m^3/yr. Measures were implemented to reduce the consumption:

- A permanent control of water consumption through an installed measurement system
- Rapid response to failure occurrences
- Increased maintenance in the water network
- Strategic low-cost repairs in the water network to eliminate leaks

This intervention allowed to optimize water use and resulted in savings in water consumption, see Figure 3.5.

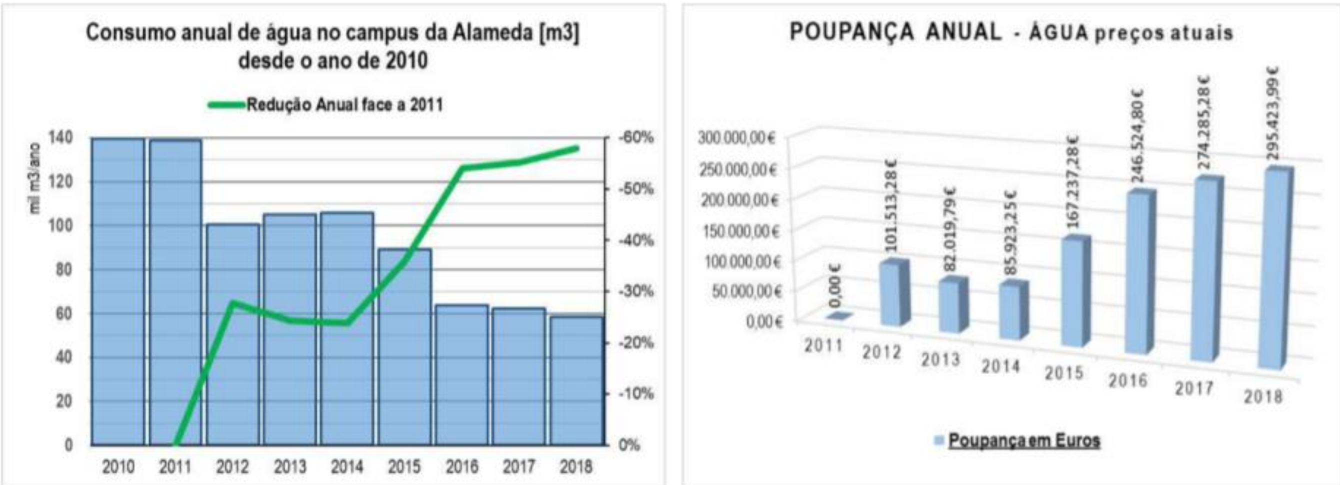

Figure 3.3- Results of Técnico Sustentável in water use and annual savings, from [64]

The results indicate approximately 58% in water savings when comparing the water consumption in 2011 and 2018. It represents accumulated water savings of 387 426 m^3in the same period, according to [64]. Financially, it traduced in savings of 295 423€ for the year of 2018 and a total of over 1M € since 2011.

3.2.3 Sustainable Mobility:

The Alameda Campus is in a central area of Lisbon, easily accessed by public transports. Yet, a significant amount of Técnico's community members use a private vehicle to the campus. In 2017 two solutions were presented to promote sustainable mobility and reductions in GHG emissions: "U-Bike Portugal – Operação Técnico" and a Carpooling platform exclusive for Técnico community members.

U-Bike Portugal – Operação Técnico was developed to stimulate the utilization of bicycles for transportation. The goal is to give the community members the possibility to use a bike at an affordable price through the following measures:

- The bicycles are attributed at the beginning of each semester by prize draw.
- New parking spots for bicycles.
- Creation of a workshop at Alameda Campus to perform simple repairs.
- Implementation of Electric Vehicle chargers.

The adopted measures resulted in a good engagement of the community. According to the project [64] the number of candidates to the prize draw was 10 times superior to the number of available bikes. Técnico also promoted gaming challenges to stimulate the community members to use bicycles which were successful in members' engagement. The bicycle parking spots require an expansion, as a result of the adhesion of the community.

The carpooling platform allows the users to share car rides to Técnico. 20 months after its creation, this platform had 1 017 members and 310 registered vehicles. The results of the adhesion to the platform are expressed in Table 3.3.

Number of members	1 017
Number of registered vehicles	310
Number of drivers with offered rides	69
Number of itineraries with different routes and schedule	82
Total number of offered rides	20 279
Number of kilometres travelled for free	832 104
Total number of ride seats available	62 856
Kilometres of available rides	2 642 414

Table 3.1- Results of the carpooling platform 20 months after its creation

According to [64] it is possible to estimate that the utilization of the platform allowed, until 2019, savings of approximately 210 000 litres of fuel, which represents up to 340 tCO_2eq and 300 000€ in fuel [64].

3.2.4 Residue treatment and recycling:

The Alameda Campus is equipped with trash bins for paper, plastic and metal, glass, electronic residues, batteries, used oils, hazardous chemical residues, biologic residues, and construction and demolition residues. The residues are collected and treated by municipal entities or specialized companies collaborating with Técnico.

The biggest adversity regarding the sustainable management of residues regarded the difficulties in the measurement of produced residues. This issue was addressed by implementing some measures:

- Differentiate the waste collection for each facility.

- Community sensibilization regarding sustainable residue treatment and production practices.
- Establish contractual clauses to lead the suppliers to take responsibility for sustainable waste production and management.

3.3 Services and Infrastructure

3.3.1 Services

The services that the Alameda Campus provides other services than teaching and research related activities.

Chemical and Biological Analysis Lab: this lab performs analysis, with emphasis on water quality analysis. Despite being open to customers outside Técnico Community it also develops research with collaboration in national and international projects.

Bank Services: there are several ATM machines across the Campus and there is also a Santander Totta agency.

Congress Centre: the facilities offer different types of solutions, from an auditorium with 300 seats to rooms with a capacity of 20 to 80 people. The options include sound and image technologies. It hosts events organized by Técnico and by external entities in a scientific context.

Food provision: there are several canteens, cafeterias, and restaurants across the campus, where it is possible to find different types of offers and services.

Health Services: the campus hosts a clinic offering diverse medical specialties. It is open to members of Técnico Community and external customers as well.

Information and Communication Technology Services: computer and network services and application and information systems to support the data and the networks of the campus.

IST Press: it is Técnico's publishing company. It was created to publish scientific literature to promote the development of engineering and scientific research in Portugal, and to value the knowledge in Portuguese universities, specially Técnico.

Kindergarten: with a capacity of approximately 110 children aged from four months to six years old.

Libraries: the campus has several free access libraries that can be used either to consult information or as a physical space where students can study.

Museums: the campus hosts the museums Alfredo Bensaúde and Décio Thadeu in Pavilhão de Minas and the Museu de Engenharia Civil in Pavilhão de Civil, pavilhão desportivo where science and engineering patrimony is preserved and exposed.

Sports facilities: the facilities include outdoor futsal, tennis and padel courts, an indoor sports hall, a swimming pool, and a locker room. The facilities can be rented by community members and external people.

Stores: the campus hosts the Técnico Shop, where merchandising of Técnico is available, and the smallest FNAC store in the world.

Study area: there are several rooms available for the students to work. Some rooms are open every day of the week, 24 hours a day.

The description of the services provided by the campus acknowledges the diversity of the infrastructures of the campus. The diversity of buildings and the equipment installed in each one makes the Alameda Campus a unique place to conduct experiments in a real-life context. The partners that will join the CALL will not only have access to a testbed where research and development can be developed, but as well as the data that is associated with the services functioning on the campus.

3.3.2 Infrastructure

The project "*Técnico - Campus Sustentável*" [59] resulted, among other, in an energy audit and inventory of all the equipment and the consumptions of the campus. It is known exactly what equipment is used in each building and its consumption of electrical energy.

The equipment present in each building is organized in different categories, which allows to knowing the highest and more relevant energy consumers of each building.

The equipment categories are:

- HVAC: the HVAC equipment is divided into 2 typologies, the distributed HVAC and the central HVAC, where the first one corresponds to equipment that is controlled directly by its user, and the second one to equipment that is controlled from the electric power board, normally by the person in charge of the building operations. The distributed HVAC normally features equipment such as portable AC units, heaters, dehumidifiers, split AC units, extractors, and fans, as the central HVAC equipment is generally characterized by hydraulic pumps, boilers, chillers, dehumidifiers, extractors, multisplit AC units, rooftop units (RTU), air handling units (AHU), fans, fan coil units, variable refrigerant flow units (VRF). The nominal thermal power, nominal electric power and energy consumed per year is also known for each type of equipment.

- Computers: this category of equipment features servers, CPU units (conventional, clusters and workstations), desktops (CRT and TFT), CRT screens, LCD screens, printers with fax, inkjet printers, laser printers, laser work centre printer, scanners, servers, ATM machines, and others. The nominal electric power and energy consumed by each piece of equipment is also known.

- Common Systems: this category includes equipment that serves or is used by every user in each building, such as CCTV systems, cargo lifters, residual water and fire water network pumping, centralized compressed air system, and elevators. The nominal electric power and energy consumed are known for each piece of equipment.

- Catering: this category regards equipment used to make or preserve food and drinks all across the campus, such as, fridges, freezers, water supply machines, kettles, coffee machines, coffee vending machines, microwaves, electric stoves, toasters, and vending machines. The power and energy consumed by each piece of equipment are known.

- Electrical plug-in equipment: this category regards equipment connected to electric plugs, normally connected and disconnected by the user. The equipment considered in this category is not considered in the category "Computers". The devices featured in this category are sound equipment, lamps, mobile phone chargers, telephones, DVDs, photocopiers, electric guillotine paper cutter, washing machines, clothes dryers, plotters, electric doors, projectors, TV's (LCD and CRT), thermoaccumulator, among other. The electric power and energy consumed by each piece of equipment is estimated.

- Lighting: this category regards all the lighting equipment existing on the campus. It includes both indoor and outdoor lighting equipment across the campus. The quantity of each piece of equipment is known, as well as the respective power. The utilization period is estimated to calculate the consumed energy.

- Research equipment: this category regards equipment that is used in laboratory activities. Equipment considered in previous categories is not included in research equipment. An inventory was performed on the quantity of equipment and the respective power. The utilization period of each piece equipment was estimated to calculate the consumed energy.

With all the available data from "*Técnico - Campus Sustentável*", the equipment existing in each building and its respective energy consumption were organized in tables. For each system of each building there is a table where the equipment is listed, as well as the quantities of each equipment, the power, and the energy consumption, similar to Tables 3.1 and 3.2.

SYSTEM	EQUIPMENT	QUANTITY	NOMINAL THERMAL POWER (kW)	NOMINAL ELECTRICAL POWER (kW)	ENERGy CONSUMPTION (kWh/yr)
Common HVAC 	Circulation pump (*Chiller*)	46		0,07 to 10 (Avg 3,36)	217 969
	Reversible heat pump (Operating as a *Chiller*)	2	393	145	138 144
	VRV (Exterior Unit)	4	20,8 to 28 (Avg 24,8)	8 to 10,89 (Avg 9,61)	86 503
	Ventilator	43		0,1 to 5,5 (Avg 0,98)	84 447
	AHU	13	15,6 to 115,8 (Avg 67)	5,2 to 38,6 (Avg 22,3)	67 585
	Heat pump (Split Exterior Unit)	98	1,3 to 16,1 (Avg 6,15) 1,5 to 19,1 (Avg 7,07)	0,43 to 5,37 (Avg 1,88) 0,5 to 6,37 (Avg 1,93)	37 451
	Chiller	1	25	9,76	28 789
	FAHU	6	0,62 to 7 (Avg 2,9)	0,21 to 2,33 (Avg 0,97)	21 724
	VRV (Interior Unit)	9	4,5 to 16 (Avg 9,36)	0,2 to 0,4 (Avg 0,26)	7 298
	Cooling Tower	1	66	22	4 984
	TOTAL				**694 893**

Table 3.2-Central HVAC "Pavilhão de Civil"

In most Alameda Campus' buildings, the Common HVAC system represents the largest source of electric energy consumption. Table 3.1 regards the Common HVAC system of Pavilhão de Civil. This system is responsible for 53% of the total electrical consumption of the building, which represents 694 893 kWh/yr. As expressed in Figure 3.2, the second bigger energy consumer of Pavilhão de Civil is the Lighting system, followed by the computers system.

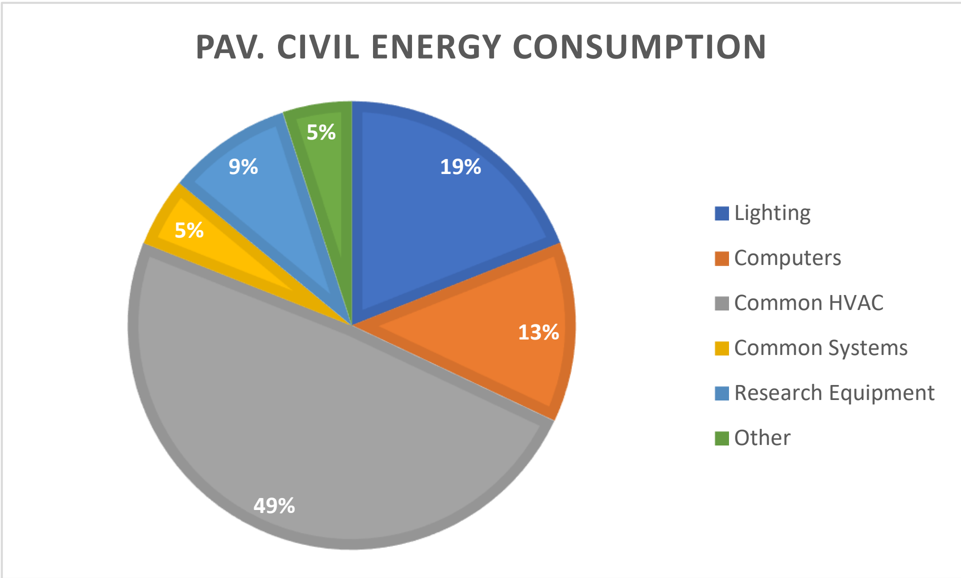

Figure 3.4- Pavilhão de Civil Electrical Energy consumption by system

Unlike most of the buildings of the campus, the Pavilhão Central's largest electrical energy consumption regards computer equipment. The list of each individual equipment that composes this category, its power and energy consumption is listed in Table 3.2.

SYSTEM	EQUIPMENT	QUANTITY	ELECTRICAL NOMINAL POWER (kW)	CONSUMED ENERGY (kWh/ano)
Computer 	Server	20	0,4	807 905
	Desktop Computer + LCD	423	0,435	78 062
	Computer Cluster	9	0,4	52 416
	Desktop Computer + CRT	53	0,52	12 284
	Shared Printer (work center)	105	0,58	10 391
	Photocopier	1	3	4 335
	Laptop	109	0,04	2 152
	Other			21 225
	TOTAL			**988 770**

Table 3.3- Computer Equipment "Pavilhão Central

This type of equipment is responsible for an electricity consumption of 988 770 kWh/yr, which represents 67% of the building's consumption, see figure 3.3. This building hosts all the servers that run multiple platforms, such as, Técnico online Platform "Fénix", the servers for Técnico Webmail, among others. The servers are responsible for a consumption of 807 905 kWh/yr of electrical energy. The Common HVAC system is responsible for a consumption of 327 727 kWh/yr and the Lighting for 104 060 kWh/yr, which are equivalent to 22% and 7% of the total electrical energy consumption of the building, respectively.

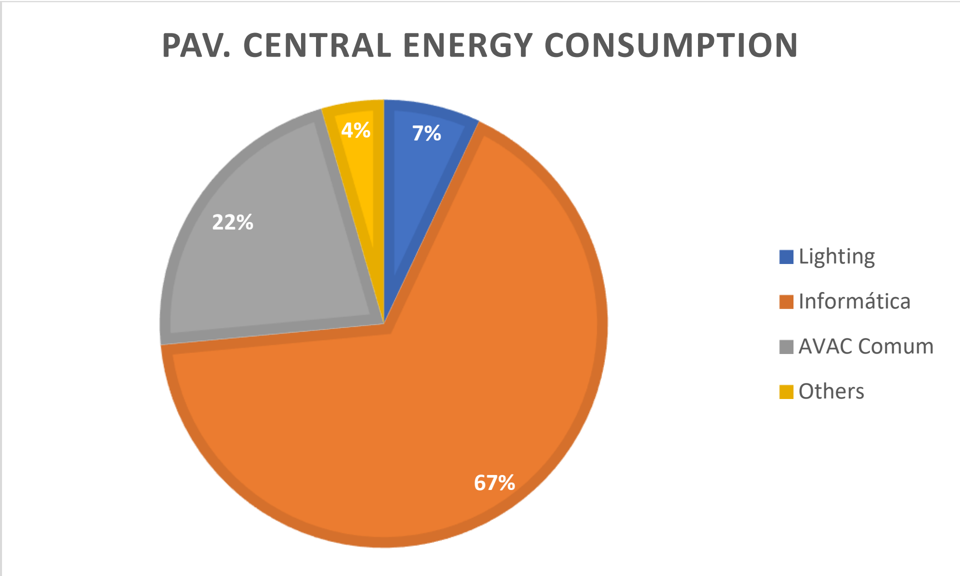

Figure 3.5- - Pavilhão de Central Electrical Energy consumption by system

Tables 3.1 and 3.2 and Figures 3.1 and 3.2 are examples of the type of data that the CALL intends to make available to partners that are willing to participate in Living Lab activities specially focused on energy sustainability. This material gives a blueprint of Técnico’s equipment and needs, and it allows partners to know what kind of services or technologies could be tested at the Alameda Campus.

3.4 IST Partners Network

Técnico Technology Transfer Office oversees Técnico Partner Network. The actual partner network of Técnico allows the establishment of a relationship between the partners and Técnico's community (students, teachers, researchers, and staff). The partnerships are made with the belief that they represent a unique opportunity to benefit both parties involved (Técnico community and partners). There are 5 dimensions of activity in the partnerships: Meeting New Talents, More and Better Talents, Innovation Accelerator, Social Responsibility, and Participation in Orientation of IST Strategies [65], represented in Figure 3.6.

Figure 3.6- The 5 dimensions of partnerships

The Meeting the New Talents activities allow partners have premium access to Técnico Job Banks, participation in student's events, personalized meetings with students and marketing towards Técnico's community. The partners have the advantages over other companies as they have the possibility to be the first to contact Técnico's community.

More and Better Talents regard activities to stimulate the community to do better, whether it is by attributing awards or by organizing formations and learning programs, such as scholarships and merit awards, sponsorship of facilities and equipment, professional formations and actualization of Collaborators and involvement in innovative learning programs.

The innovation Accelerator dimension can be seen as a part of a Living Lab itself. Many innovative solutions occur when there is a collaboration between the responsible for knowledge production (researchers) and the ones who are aware of the needs of the markets (industry/partners). The activities for this purpose are Investigation and Development Projects, Meetings with Professors and Researchers, seminars on intellectual property, and sponsorship of investigation areas.

Social Responsibility is associated with the contribution that the partners are giving to society when supporting IST. Companies with social responsibility have a special concern on how their actions can have a positive output to the rest of the society, not only because it is morally correct but also because they can benefit from a marketing standpoint. The activities developed regarding social responsibility are the involvement and use of Técnico Learning Centre and the support of social awareness activities.

The last dimension of the partnership is the participation in the orientation of IST strategies. The meetings with Técnico's President to discuss orientation strategies and the participation in the advisory board allow the partners to have their input and to be aware of how Técnico is administrated.

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4. Developing strategies for IST Campus as a Living Lab on Energy and Entrepreneurship: The CALL initiative.

4.1 The Governance

The CALL is a creation of the Energy Initiative. The Energy Initiative is a Transversal Structure in the layout of Técnico's governance, from [66], see Figure 4.1

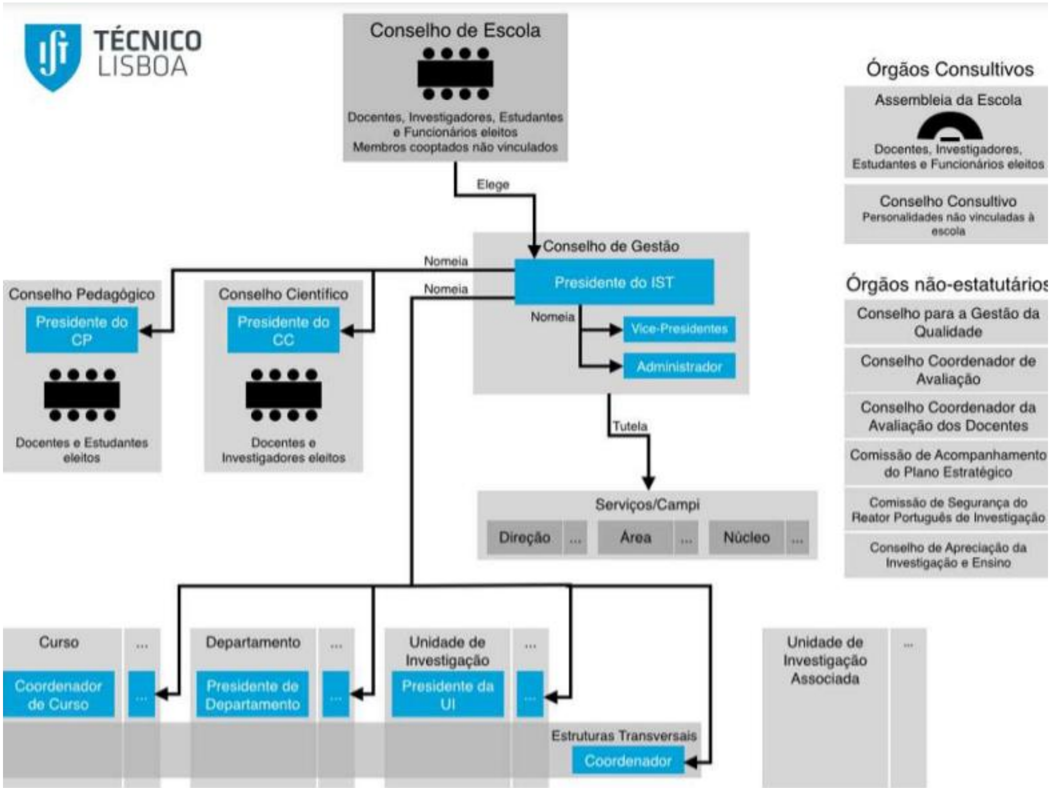

Figure 4.1- Técnico's Governance chart, from [65].

The Transversal Structures (Estruturas Transversais) represented in figure 4.1, are structures which activities have an impact in different courses, departments, and investigation units. The Energy Initiative is responsible for developing sustainability measures in the Campus, with a special emphasis on energy use. The working group includes Professors and Researchers who came up with the idea of the Campus as a Living Lab.

The CALL, being developed under the supervision of the Energy Initiative, a Transversal Structure, will have animpact in different courses, departments, and investigation units, Figure 4.2

The Technology Transfer Office includes the "Núcleo de Parcerias Empresariais", which is the Core of Corporate Partnerships. This core is not related to the Transversal Structures, Figure 4.2.

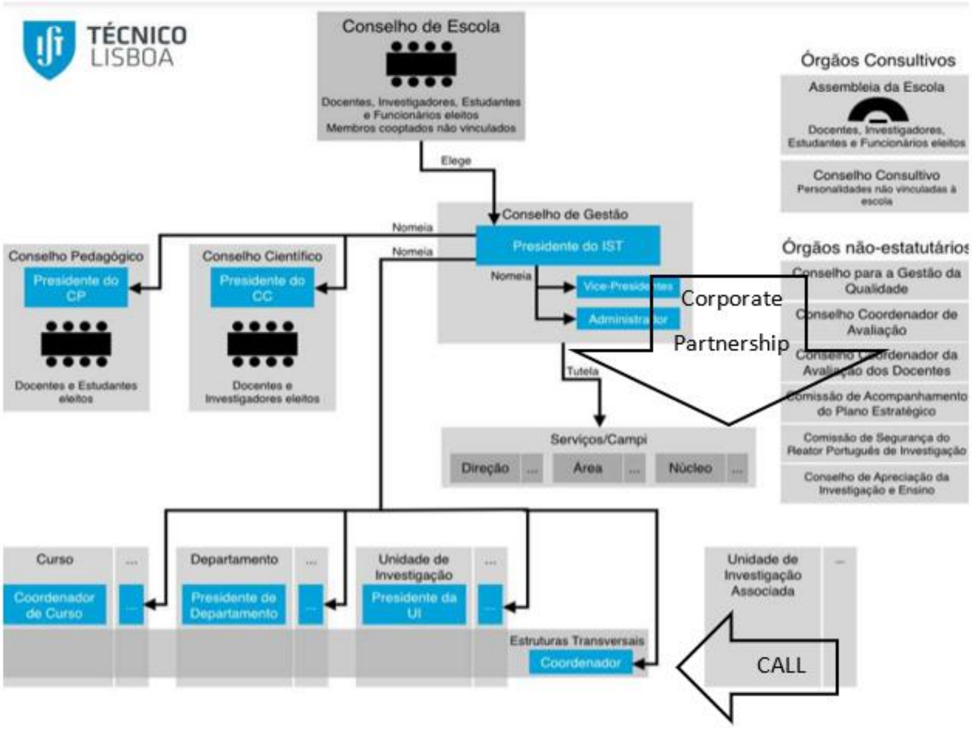

Figure 4.2- Insertion of the CALL in IST Governance Structure

As expressed in Figure 4.2, the CALL and the Core of Corporate Partnerships are not directly connected. However, for the purpose of creating new partnerships, a direct interaction between both working groups could enhance the capacity of creating new partnerships. The Technology Transfer Office, especially its Core of Corporate Partnerships, are responsible for the Técnico Partners Network and have been successful in establishing partnerships with industry partners, thus the knowhow of the Technology Transfer Office can beneficiate the CALL. On the other hand, the CALL can also be used by the Technology Transfer Office as a new dimension in the partnerships between Técnico and Industry Partners, as explained further in "4.3.1 – Aligning ideas and financing sources - Promote industry-university relationships".

The suggested governance structure of the CALL, for the purpose of this thesis, is composed of 2 groups: Living Labs and Partnerships, as expressed in Figure 4.3.

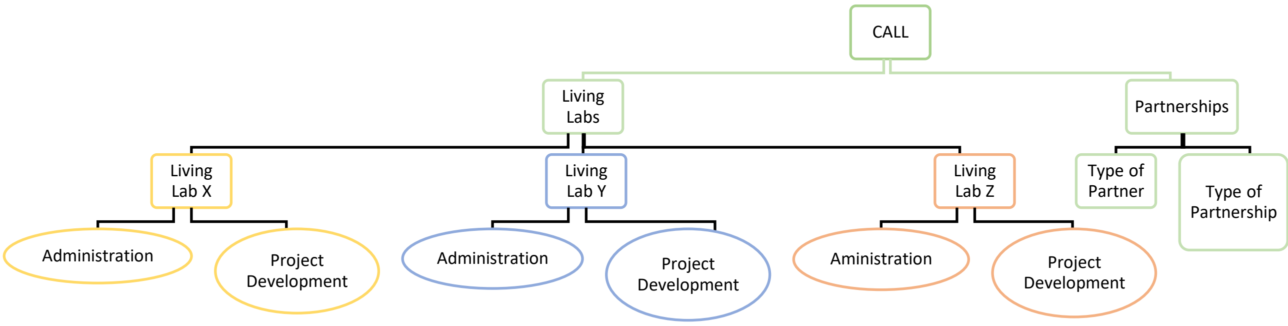

Figure 4.3- Governance Structure of the CALL

The Living Labs department oversees the administration and development of all the Living Labs to be implemented. The Partnerships department oversees the communication with partners of the CALL, either companies, other learning institutions, or public institutions. It is the partnerships department that should work in coordination with the Technology Transfer Office.

As suggested in Figure 4.4, each living lab to be developed is autonomous regarding its administration and the project development. The administration and the development of the activities should include members from different contexts of Técnico community, students, professors, research and staff members, as the inclusion of members from different contexts permits the obtention of different points of view over the activities of the CALL, stimulates the creation of new initiatives and potentially helps the CALL in growth and community engagement.

The administration of the partnerships according to the type of partner and the type of partnership is responsible for the establishment of the connection between each living lab and the partners. The types of partners and partnerships are explained further in “4.3.1 – Type of Partner” and “4.3.2 – Type of Partnership”.

4.2 Identifying and Mapping

The intention behind the creation of the CALL is to engage IST's community and allow everyone willing to participate and share their ideas. All the students, researchers and professors must be informed about the CALL and given a platform where their ideas can be shared.

4.2.1 Website design and community engagement

As the first step in the promotion of the CALL, a website (https://callforenergy.tecnico.ulisboa.pt/) was developed by the Energy Initiative, where the CALL for Energy is presented as "an effort in favour of climate neutrality, including the generation of renewable electricity, the use of innovative energy demand management solutions and the promotion of energy efficiency based on artificial intelligence, the free exchange of information from hundreds of sensors distributed by Campi or even the production of food in hydroponic greenhouses on top of buildings." The website features schemes of a possible organization of the CALL activities, see Figure 4.4.

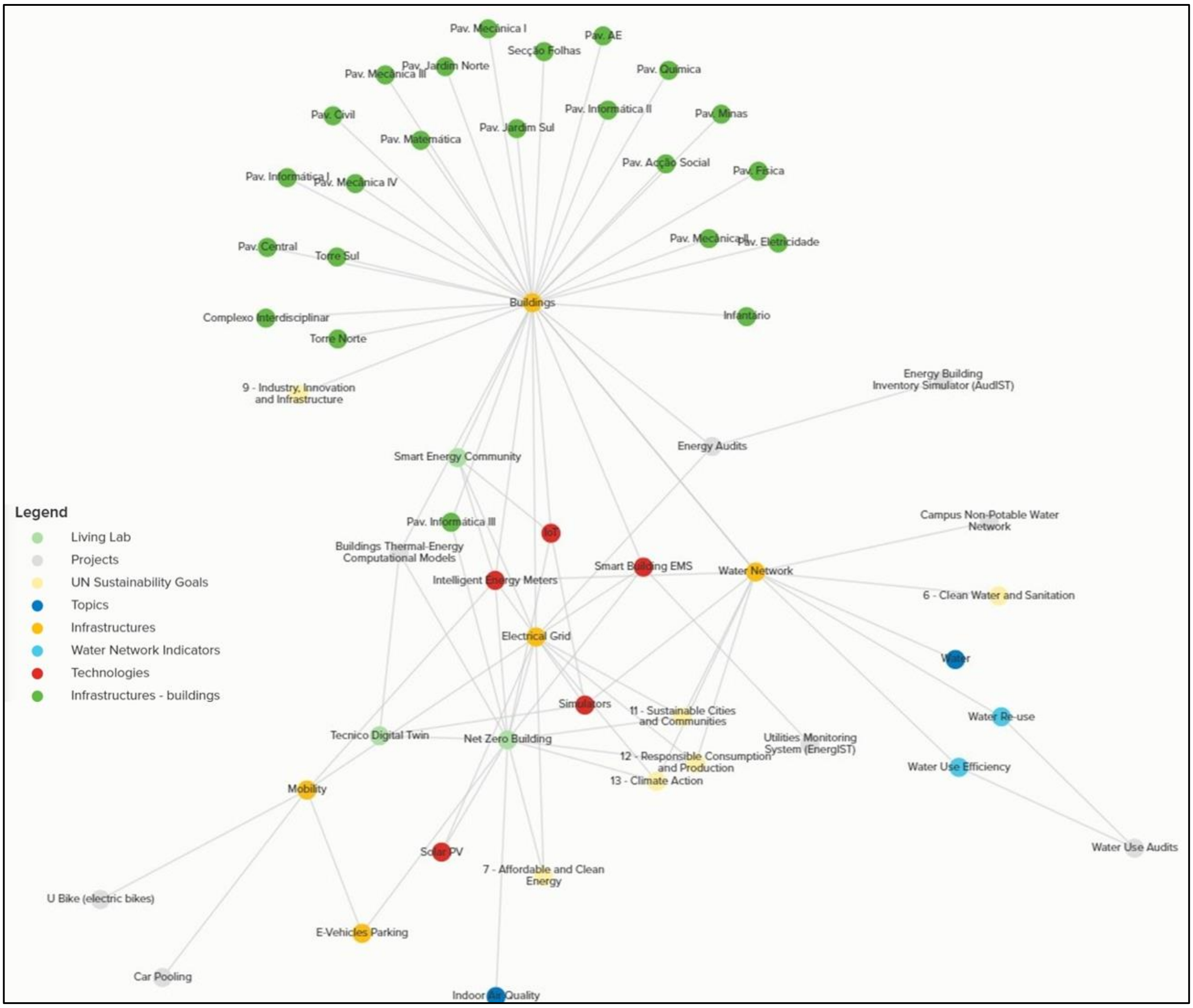

Figure 4.4- Structure example for the CALL

Figure 4.4 presents the connections and relations between eventual Living Labs, Projects, UN Sustainability Goals, Topics, Infrastructures, Technologies, and Water Network Indicators. This model represents the initial brainstorm that was made to acknowledge the intentions of the CALL organization to involve several possibilities.

This structure shown in Figure 4.4 revealed itself later to be too complex and was not as enlightening as desired, so modifications were made and it was adapted to the example of Figure 4.5, which features the ideas submitted by members of the Técnico community.

The website also presents the structure of the CALL as a structure based on the concepts of Education, Research, Infrastructures, and Collaborations, with a brief description of each one. A detailed description of these concepts is made in the next section of this chapter "4.3 Aligning ideas and financing sources - Promote industry-university relationships", which regard the approaches and the benefits of the CALL to promote the relationships between the university and industry.

To acknowledge the targeted people about the CALL, the Energy Initiative and the Governing Board of the IST sent an invitation via email to all the students, scholarship holders, staff members, researchers, and professors. The email presented the Técnico Living Lab for Energy as a new challenge and a link to a form, where the participants could submit ideas related to the concept of the Campus as a Living Lab for Energy. Approximately 20 responses containing Living Lab ideas were obtained, the vast majority from students. The ideas presented are presented in Table 4.1.

Idea	Theme
Sustainability evaluation of IST Buildings - LiderA	Sustainable Practices
Green hydrogen cycle in the campus	Energy Conversion
Energetic Efficiency of electrical systems	Sustainable Practices
Geothermal heating and cooling	Energy Conversion
Movable set of Photovoltaic Panels	Energy Conversion
Waste valorisation - “Wastes to Energy”	Sustainable Practices
Electrochemical Energy storage and conversion	Energy Conversion
Monitorization of thermal, illuminative, and energetic performance of new solutions in IST buildings	Sustainable Practices
Strategies to reduce energy consumption by using existent data	Sustainable Practices
Communal oven	Sustainable Practices
Research in coating with nanomaterial and agro-industrial residue as solution for pavements	Sustainable Practices
Triboelectric nanogenerators for energy production from footsteps	Energy Conversion
Outdoor study space equipped with solar panels	Energy Conversion
Exterior LED illumination fed from renewable energy source	Energy Conversion
Hydrogen based mobility	Mobility
Sustainable Mobility	Mobility
Net Zero EV chargers	Mobility
Net Zero Building	Energy Conversion

Table 4.1- Ideas submitted by Técnico community members

As shown in Table 4.1 each Living Lab idea is associated with a theme. The three different themes of Living Labs are Sustainable Practices, Energy Conversion, and Mobility. The Sustainable Practices represent Living Labs that aim to improve the energy efficiency of the Campus. The Energy Conversion represents Living Labs based on producing energy from renewable sources. The Mobility involves Living Labs directly related to clean mobility solutions.

The ideas for Living Labs received can also be represented in the following illustration, Figure 4.5.

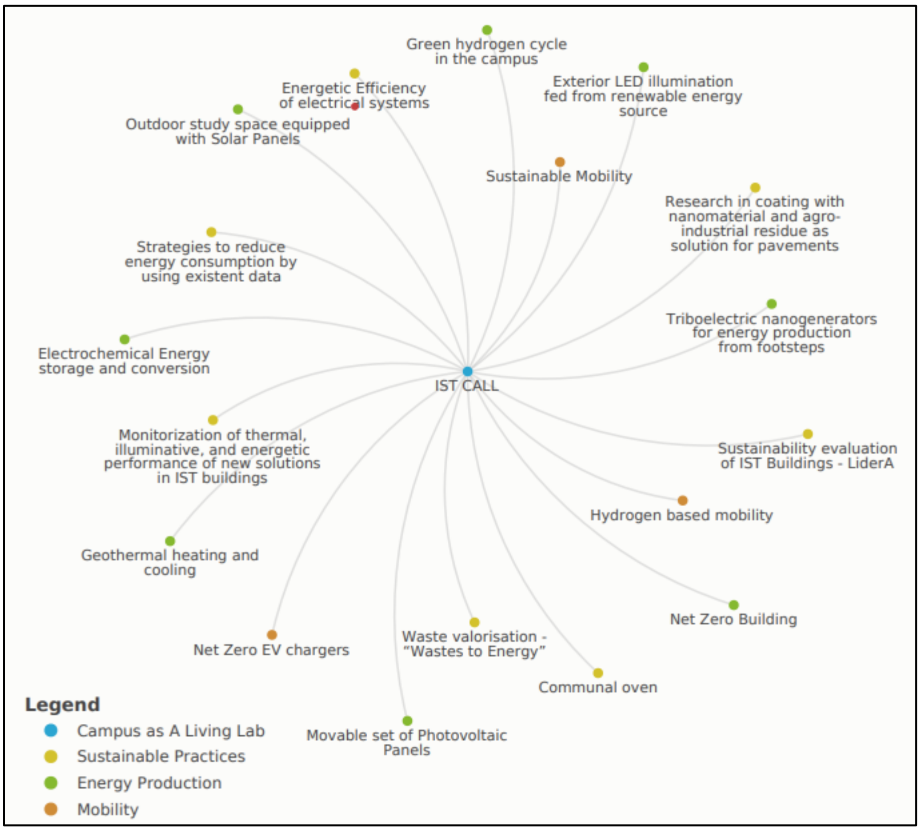

Figure 4.5- Suggestion for CALL organization

Figure 4.5 allows to later connect the Living Labs according to several criteria, whether it is by the type of technologies they use, the type of infrastructure they are related to or their relation to the industry. The central element and responsible for the creation of all the living labs is the Campus as A Living Lab project. The Living Labs are represented in three different colours according to the theme they are related to, yellow for Sustainable Practices, green for Energy Conversion, and orange for Mobility.

The same scheme from Figure 4.5 can be presented with the addition of the technologies that may be tested in each Living Lab, Figure 4.6.

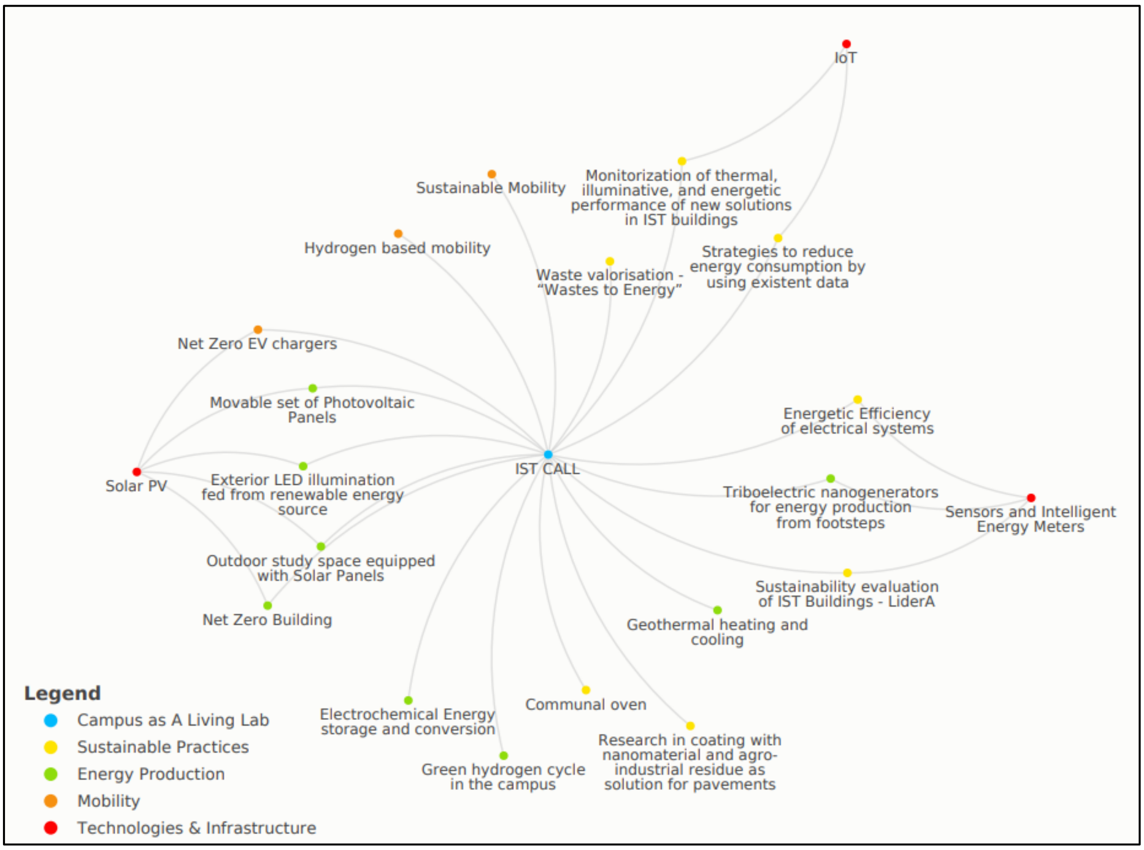

Figure 4.6- Suggestion for CALL organization, including Technologies and Infrastructure

Figure 4.6 represents the same organization of Figure 4.5 now with the addition of Technologies and Infrastructures that each Living Lab may relate to, such as Solar PV, Internet of Things and Sensors and Intelligent Energy Meters. This illustration represents only a suggestion of what can be developed in the CALL as there are other technologies that may relate to each one of the represented Living Labs.

The fluidity of the CALL allows its representation in an infinity of different maps. For example, the Living Labs may be gathered and connected according to the place of the campus where they are being developed, by the type of investment made for it, or by the type of partner they are related to.

It is important to contextualize that the email sent to the IST community to gather ideas and participants for the CALL was the first action taken to engage the community. Naturally, there is still a significant part of the community members that are not aware of the CALL. The fact that approximately 20 answers were received without any previous publicity being made to acknowledge the CALL is interpreted as an indicator of the margin of progression of this initiative. It is expected that, with investment in promoting the CALL and by stimulating the development of new Living Lab ideas, new participants from different departments will be willing to take a part in the activities, enriching the CALL with new ideas and multidisciplinary.

Once the IST community has shown to be interested in the CALL there is the need to engage partners in it. For this to happen the CALL must be very clear on the benefits that this initiative brings to the involved partners.

The development of activities with the CALL allows access to some infrastructure and data of the Alameda Campus.

4.2.2 The CALL as a Multi-Layer Platform

The Platform that the CALL intends to implement on the campus is a Multi-Layer Platform.

Professor Hugo Morais suggests the organization of the Platform in Layers to develop Living Labs across different topics with the inclusion of various technologies and services.

The activities being developed can be organized according to 5 different main layers that incorporate the tools used to develop the CALL, shown in Figure 4.7.

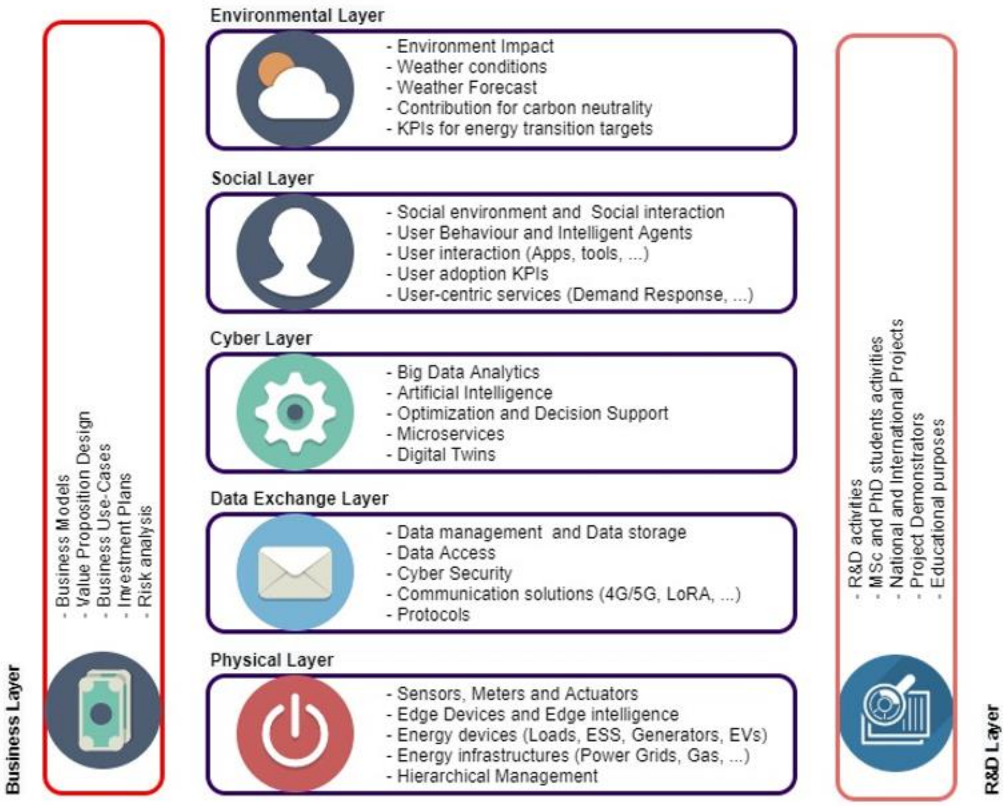

Figure 4.7- Multi-Layer platform, suggested by Prof. Hugo Morais

- Environmental Layer: regards the evaluation of the solutions that are being implemented and their impact. This is accomplished by setting goals regarding solutions on responsible energy consumption/production and by using adequate KPIs. It is focused on tracking the environmental impact of the activities and their contribution to carbon neutrality. This layer also involves a focus on weather conditions and weather forecasts for results optimization.

- Social Layer: regards the behaviour and reaction of the users (either IST community or a partner) to a service or technology, allowing to evaluate the feedback of the consumers to it in a real-world scenario before its commercialization. It relies on the use of Apps, user centric services and intelligent agents to enhance the interaction between the users and the platform, allowing data collection for posterior analysis.

- Cyber Layer: regards all the systems used for data analysis, artificial intelligence and decision making. This layer is responsible for the optimization of the systems and decision support. It involves the use of Artificial Intelligence, digital twins, and a microservices type of architecture.

- Data Exchange Layer: regards all the processes of data exchange, storage, and management. It is responsible for the connection between all the systems of the platform must feature cyber security protocols. It includes the use of communication solutions as 4G and 5G, LoRa, Blockchain, among others.

- Physical Layer: regards all the sensors, meters and actuators used in the platform. Some equipment feature decision making algorithms, which bring the need of hierarchical management to ensure a successful operation of the systems. This layer includes the use of energy devices, such as generators, energy storage systems, electrical vehicle chargers, and energy infrastructures, like power grids and smart building systems.

The two layers represented vertically in Figure 4.7, Business Layer and R&D Layer, regard respectively the component of the financial viability and the research and development activities common to all the platform.

Each project to be developed in the context of the CALL features the layers described above, however, it is evident that some activities might emphasize more some Layer than others. For example, the creation of a communal oven requires a strong interaction with the environmental, social, and physical layers and not as much with the cyber and data exchange layers.

4.2.3 Living Lab Characterization

To organize the Living Lab activities developed in the CALL it is important to characterize each Living Lab to be developed. Table 4.2 suggests a characterization board to be used.

		Dimension Definition
Dimensions of the Living Lab	**Theme**	The Living Labs are related either to Energy Conversion, Mobility or Sustainable Practices.
	Personnel	Refers to the team of people who are leading and developing the Living Lab.
	Technologies	Refers to the technologies and services that the living lab requires to be successfully developed. It must mention the layers of the Multi-Layer Platform that are involved (Cyber Layer, Data Exchange Layer, and Physical Layer are the most likely to be implicated).
	Infrastructure	Refers to the infrastructures involved in the Living Lab, either the ones that already exist on the Campus and are implicated in the Living Lab or the ones to be implemented. The infrastructures include buildings, energy devices, energy infrastructures, and other equipment that might be used.
	UN Goals	Refers to the UN Sustainability Goals that the Living Lab addresses.
	Funds	Refers to the budget for the Living Lab development. The expected funding sources are Private/Industry Partners and Public/government entities.
	Partnerships	Refers to the partnership(s) made for the creation of the Living Lab. This dimension includes a description of the contribution the Living Lab requires.
	Outcomes	Refers to the outcomes of the Living Lab and their impact on the Campus, the University and the community.

Table 4.2- Living Lab dimensions

Table 4.2 must provide a clear description of the Living Lab, similarly to an “identification card” of the Living Lab.

The theme of the living lab corresponds to one (or more) of the themes described previously in this chapter and in Table 4.1.

The Personnel must identify the administration of the living lab and it is likely to be composed of Professors, Students, Researchers, IST Staff Members and Partners. This dimension might also answer the following question: Who designs and develops the Living Lab? – The goal of the CALL is to have 2 possibilities:

1) By the initiative of the IST's government: this approach refers to activities designed and developed by an entity directly related to the administration of the IST, as the governing board or the sustainability office. This type of process was described previously in "2 Literature review on University LL" as the Top-down Approach.

2) By any member of the IST community: this approach refers to activities designed and developed by any member of the IST community willing to participate in the CALL, whether they are Professors, Students, Researchers or Staff members. The activities can also be driven by partners willing to join the CALL. This type of process was described previously in "2 Literature review on University LL" as the Bottom-up Approach.

The Technologies include the services and technologies used in the Living Lab, mainly for data access, exchange, management and storage, Artificial Intelligence, communication, optimization, decision support. Services such as 4G/5G, Blockchain, LoRA, Digital Twins, Apps, and APIs are likely to be implemented in the activities.

The Infrastructure consists of all the equipment, energy devices and energy infrastructures. As described previously in "3.2 Services and Infrastructure" the electrical energy consuming equipment was categorized for "Técnico – Campus Sustentável" according to the system they are a part of as HVAC (local and common), Computers, Common Systems, Catering, Electrical plug-in equipment, lighting and research equipment. For the purpose of the Living Lab description, the infrastructure dimension can make use of the same categories to illustrate the equipment used in the Living Lab, providing a contextualization of the Living Lab in the whole campus activity. For each building of the Alameda Campus there are tables for each system, with a detailed inventory of the existent equipment and their respective energy consumption, as well as the energy consumed by each system. This is relevant information to develop Living Labs related to different themes in the campus, as some of the existent equipment may be used to test or develop new services and technologies.

Each Living Lab being developed aims to address at least one of the UN 17 SDGs. To track the goals of each living lab and their impact on a broad perspective it is important to connect the activities being developed to larger standards and common goals.

Every Living Lab will require a fund to be developed, mostly for acquisition of the equipment, services, and technologies. Since the CALL can't rely on IST's budget to fund the Living Labs, other financing sources and sponsorships are required. The main financing sources are private/industry partners or public/Government partners, the details to partnerships for funding are explained in "4.3 Aligning ideas and financing sources - Promote industry-university relationships".

The Partnerships refer to the entity that is supporting the Living Lab, mainly to finance it. The partnerships may occur either by an offer from the partner or an invitation/application from the governance of the Living Lab, as explained later in "4.3.5 From CALL to Technology Transfer Office (Core for Corporate Partnership)" and "4.3.6 From Partners/Technology Transfer Office (Core for Corporate Partnership) to the CALL".

The Outreach dimension traces the effects of each Living Lab, as a successful Living Lab must have positive impacts on Técnico and its community. The outcomes can manifest in many different fields, whether it is with reductions/optimizations on energy or resources consumptions, cleaner energy consumption, or improvement of the life on campus.

4.2.4 Connecting the Living Labs dimensions to the Layers of the Platform

A clear description of the Living Lab is fundamental not only to help to its identification but can be used as a tool to raise partners for it.

The description of each dimension of the living lab must work as an “invitation card” for partnership engagement.

The dimensions of the Living Lab can also be associated with the layers of the Multi-Layer Platform, Table 4.3.

		Multi-Layer Platform				
		Environmental Layer	**Social Layer**	**Cyber Layer**	**Data Exchange Layer**	**Physical Layer**
Dimensions of the Living Lab	**Theme**					
	Personnel		Who is involved?			
	Technologies	Predict and Track the progress	Who uses them? What is the feedback? (Apps, APIs)	Artificial Intelligence, Digital twins	4/5G BlockChain LoRA LonWorks Knx Modbus	Sensors Meters Actuators
	Infrastructure	Lead to improvements: Reduce consumptions, reduce emissions	Improve life on campus			Energy Devices Energy Infrastructures Other equipment
	UN Goals	4, 5, 6, 7, 9, 11, 12, 13, 17				
	Funds	How much will the Living Lab cost?				
	Partnerships	Who will support each Layer?				
	Outcomes	What was achieved in each Layer?				

Table 4.3- Relation between dimensions of Living Labs and Layer of the Platform

The table 4.3 indicates how the dimension of each Living Lab is connected to the Layers of the Platform.

4.3 Aligning ideas and financing sources - Promote industry-university relationships

4.3.1 What we have to offer

Table 4.1 confirms that universities are fertile in ideas and projects to be developed, however, none of them can flourish without financing. The biggest challenge associated to the concept of the CALL is to bridge the gap between projects to be implemented and eventual financing sources.

As previously described in “3. Status of Energy Management and Entrepreneurship activities at IST”, the large diversity of services and infrastructures offered by the Alameda Campus, as well as all the data associated to the users of the campus, represent a wide range of possibilities to use the Campus as a tested bed for new solutions. Figure 4.8, adapted from [56] represents a scheme that describes the use of the Campus as a Living Lab.

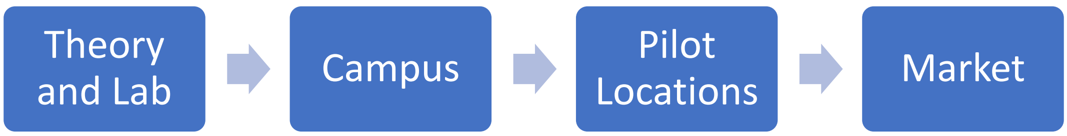

Figure 4.8- Use of the Campus as a Living Lab, adapted from [53]

Figure 4.8 demonstrates how tests can be performed in campus, to later be evaluate to pilot locations and be commercialized.

4.3.2 What we need

All the ideas noted on the previous section require investment in material, technologies and equipment that is not reasonable for the IST to afford for on its own.

The two sources expected for the financing of the CALL can be characterized by type of partner:

1) Industry entities - private entities
2) State funding - government.

The main outcomes expected from the financing sources are:

1) <u>Direct sponsorship to Living Labs</u>: the partners (private or public entities) have a direct input in the Living Lab. It can be done merely to help the project, either with material or by financing, or it can be done with the intention of testing a service or technology in a real-world scenario as the IST Campi are.
2) <u>The creation of the “tools”</u> - described in “2 Literature Review on University LL” to stimulate the creation of Living Labs – funds, courses, grants, research.

Figure 4.9 represents the different types of partners and types of partnership to interact with the CALL.

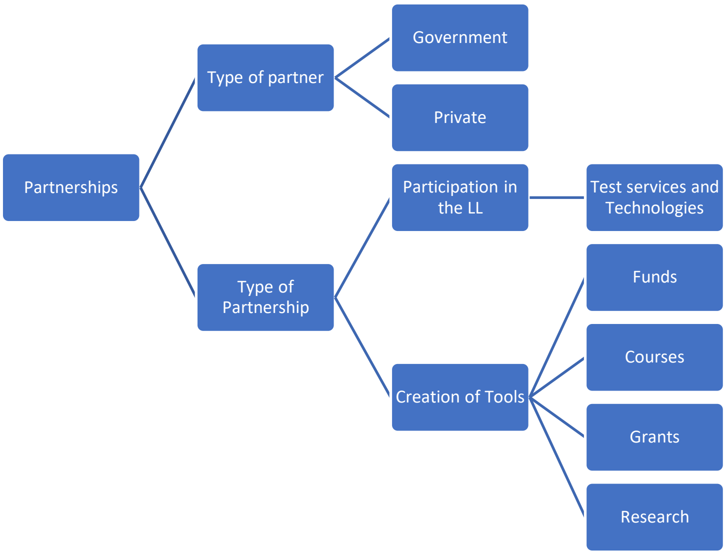

Figure 4.9- Types of Partners and Types of Partnerships

4.3.3 – Type of Partner

Private/Industry Partners:

As Industry partners the CALL expects companies interested in the utilization of the campus as a test bed. In exchange there is the possibility for the partner to integrate the Técnico Partners Network, previously presented in “2.4 IST Partners Network”.

The CALL expects to promote the industry-university relationships with the inclusion of the CALL as a new dimension in the structure of Técnico Partners Network, Figure 4.10

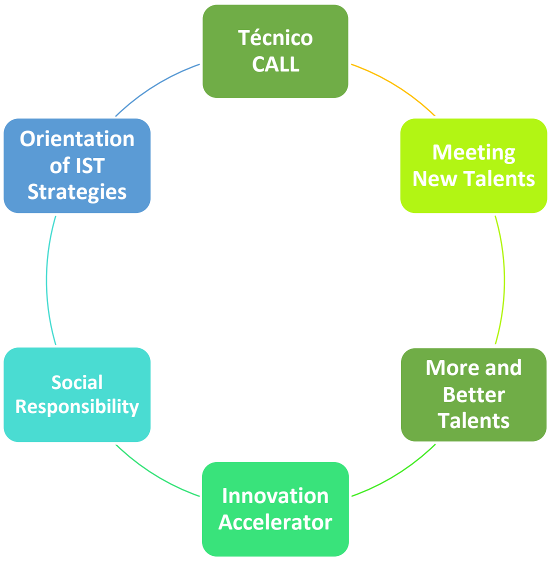

Figure 4.10- The CALL as a new dimension in Técnico Partners Network

The CALL is presented to the partners as a new challenge: to transform the campus in a Living Lab – Campus as a Living Lab, where everyone is invited to develop, create, test and implement new technologies and solutions Climate Neutral in an environment of co-creation. The activities must include research and innovation as well as the management of the campus infrastructures, while trying to engage companies/partners to provide financial support.

The activities developed by the CALL have outcomes on the concepts of Collaboration, Research, Campus Organization and Education, Figure 4.11.

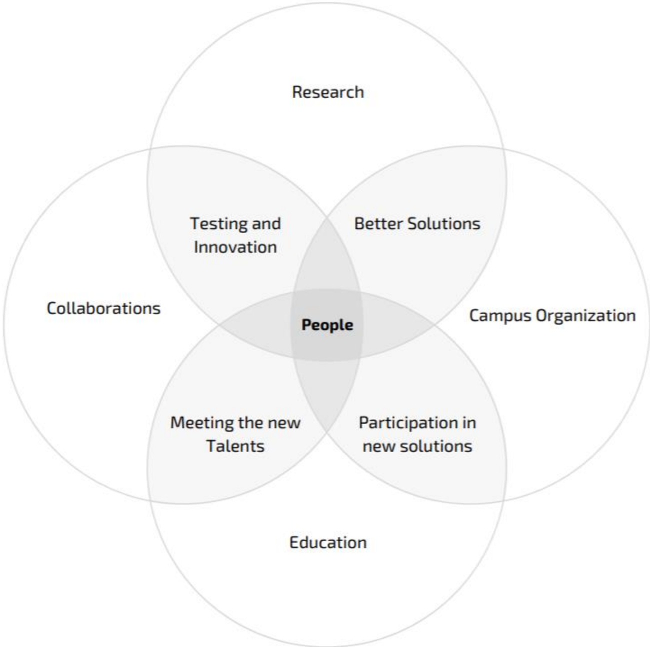

Figure 4.11- Outcomes of the activities developed by the CALL

Collaborations: The collaborations are made to contribute to a connection between Técnico's Community (Students, Professors, Researchers, Staff and Administration) and its Partners (Companies and Other Learning Institutions), promote the use of Campuses to conduct experiments pilot for climate neutrality, making Técnico a dynamic test platform open to the outside world.

Research: Research and Development are relevant in multidisciplinary areas and lead to Innovation and Development, which represent valuable assets for companies and start-ups. The Living Lab concept promotes the interaction between Partners and Técnico Community in favour of research, allowing the achievement of goals of mutual interests.

Campus Operation: The Call for Energy implies efforts towards Carbon Neutrality, thus requiring the conception of a more sustainable Campus, including the generation of renewable electricity, the use of innovative solutions for energy management and the promotion of energy efficiency based in Artificial Intelligence, the data sharing between hundreds of sensors across the Campus and even the production of food in hydroponic greenhouses on building rooftops. The involvement of Corporate Partners will allow to go further and to create new products and services that must be commercialized later to contribute to socioeconomic development. All this can be based in the use of Técnico's infrastructures, with the involvement of Técnico Community in test and optimization of new technologies and services.

Education: The Education is traditionally the focus of any University and the concept of Living Lab can reinforce this dimension with different articulations, whether it is between Partners and Students (involvement of Partners in courses of different subjects) or the involvement of Students in Campus Operation, allowing the Students to be active in projects for Campus refurbishment towards sustainability, taking advantage of the experience at Técnico and the infrastructures, betting on "learning by doing". Examples are projects to promote energy efficiency, intelligent equipment management, heating and cooling systems, charging electric vehicles, and promoting more rational use of energy. Involving the Students in Collaborations (whether with Partners or Técnico's Administration) contributes for their integration in Corporate World and in Tecnico Community.

Public Partners (Government)

As the Portuguese Government faces a Recovery and Resilience Plan (RRP) for mitigation of socio-economic impacts of COVID-19, there is an intention to apply funds towards Digital Transition, being that one of the measures to do so is the creation of a National Test Beds Network. The Recovery and Resilience Plan (RRP) dedicates 450 M€ to Digital Transition of Companies, which include the creation of a National Test Beds Network "through infrastructures that aim to create the necessary conditions for the companies to develop and test new products and services to accelerate digital transition, whether it is a physical place or a virtual simulation"[67].

Any monetary support provided from this purpose will be used either for funding specific Living Lab or to develop courses, grants and resource focused on climate neutral solutions and technologies.

4.3.4 – Type of Partnership

As illustrated in Figure 4.9, the partners can contribute either by direct participation in the activities of a specific Living Lab or by collaborating with the CALL in the creation of tools to support it.

4.3.4 – Collaboration between the CALL and the Technology Transfer Office

A direct collaboration between the CALL and the Technology Transfer Office, specially the Core for Corporate Partnership, is seen as a very important asset to engage partners. The communication can be made in both ways, from the CALL to the Technology Transfer Office or from the Technology Transfer Office to the CALL, Figure 4.12.

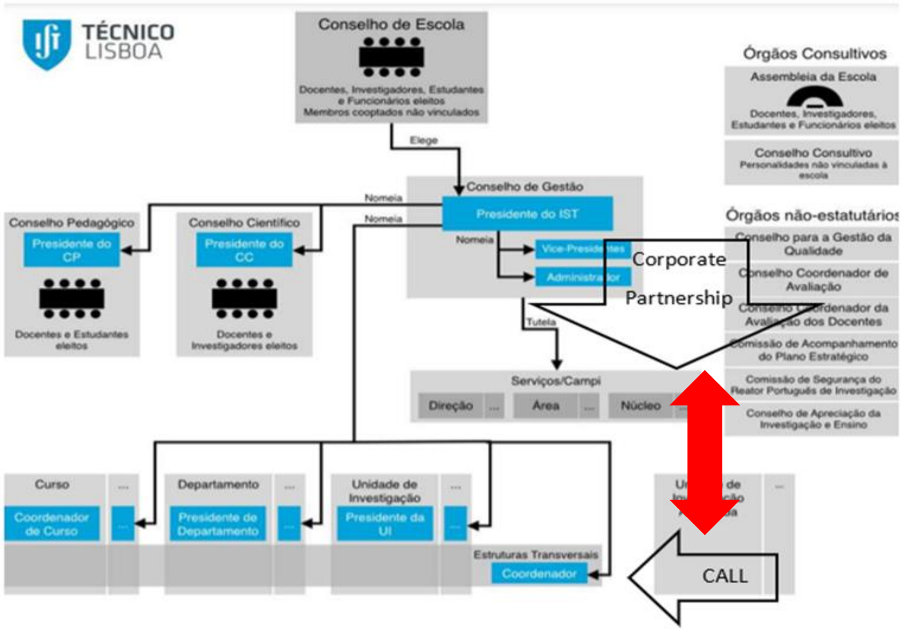

Figure 4.12- Interaction between the CALL and the Technology Transfer Office

The interaction represented in Figure 4.12 can occur in the following ways:

1) CALL to Technology Transfer Office (Core for Corporate Partnership).
2) Technology Transfer Office (Core for Corporate Partnership) to CALL.

4.3.5 From CALL to Technology Transfer Office (Core for Corporate Partnership)

This type of interaction will occur when the CALL will be developing a Living Lab and request the Technology Transfer Office for partners to support it, figure 4.13.

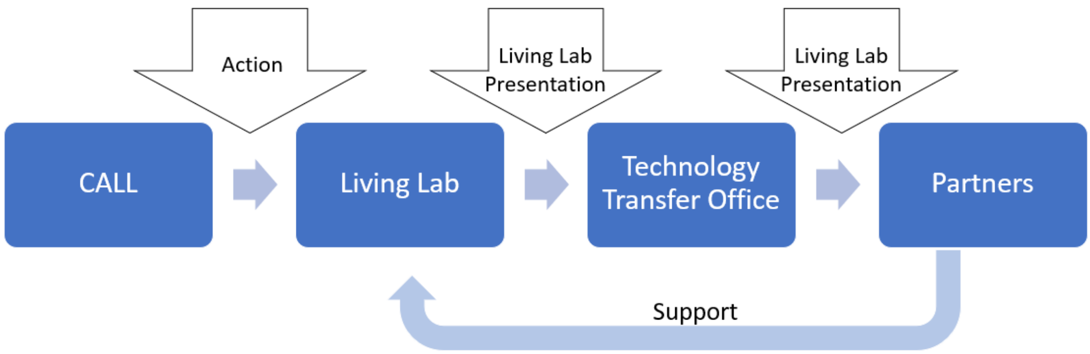

Figure 4.13- From the CALL to the Technology Transfer Office to engage partners

Figure 4.13 sequences the actions for the obtention of partners/support a Living Lab. It starts with a plan of a Living Lab which materialization requires support, either material or funding. The CALL can then present the project to the Technology Transfer Office, for example, by the tables presented in "4.2.3 Living Lab

Characterization". Subsequently, the Technology Transfer Office introduces the members of Técnico Partners Network to the upcoming Living Lab and eventually an interested Partner can be involved in the activities.

4.3.6 From Partners/Technology Transfer Office (Core for Corporate Partnership) to the CALL

This type of interaction will occur when the Partners need to test services or technology, or have ideas, figure 4.14.

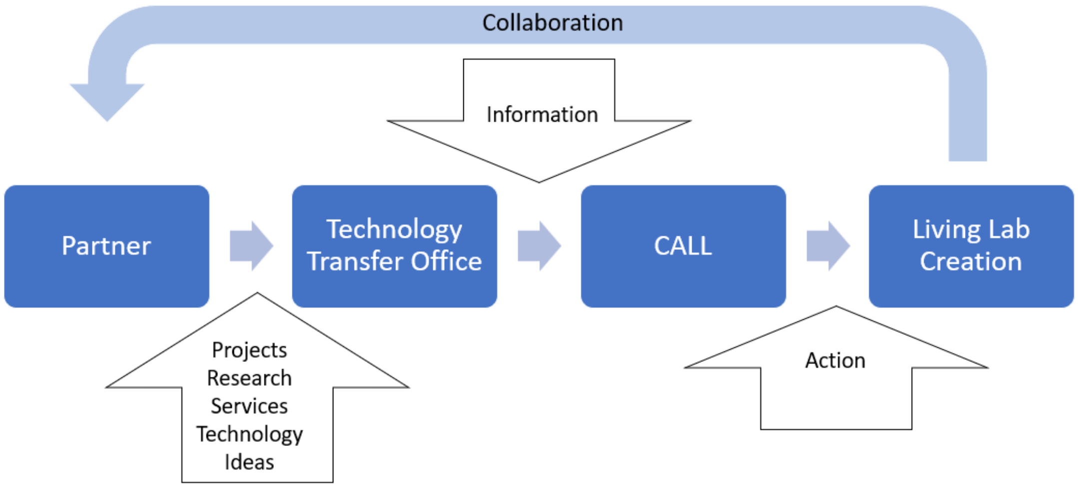

Figure 4.14- From Partners to the Technology Transfer Office to use the CALL

Figure 4.14 sequences the actions for that take place when an industry partner is interested in testing a new product, service, or technology. The partner will manifest its interest to the Technology Transfer Office that then presents the situation to the CALL. Finally, if there is interest in it, the CALL can develop a Living Lab in collaboration with the partner and make use of the Campus to test the product, service or technology in a real-world scenario.

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5. Analysis of a case study

5.1 Net Zero Building

A practical case study was developed as an example of a Living Lab that can be developed in the Alameda Campus.

The hypothesis consists of the conversion of a building of the Alameda Campus into a Net Zero Building.

5.1.1 Building Characterization

The building chosen for this purpose is the Pavilhão de Informática II, identified in Figure 5.1.

Figure 5.1- Location of Pavilhão de Informática II in the Alameda Campus

This is a ground floor building that hosts a library, 2 meeting rooms, 8 offices, a multipurpose room, a storage room and male, female and accessible toilets. The entrance of the building leads to the central atrium, where there are 2 interior gardens. The floor plan of the building is represented in Figure 5.2.

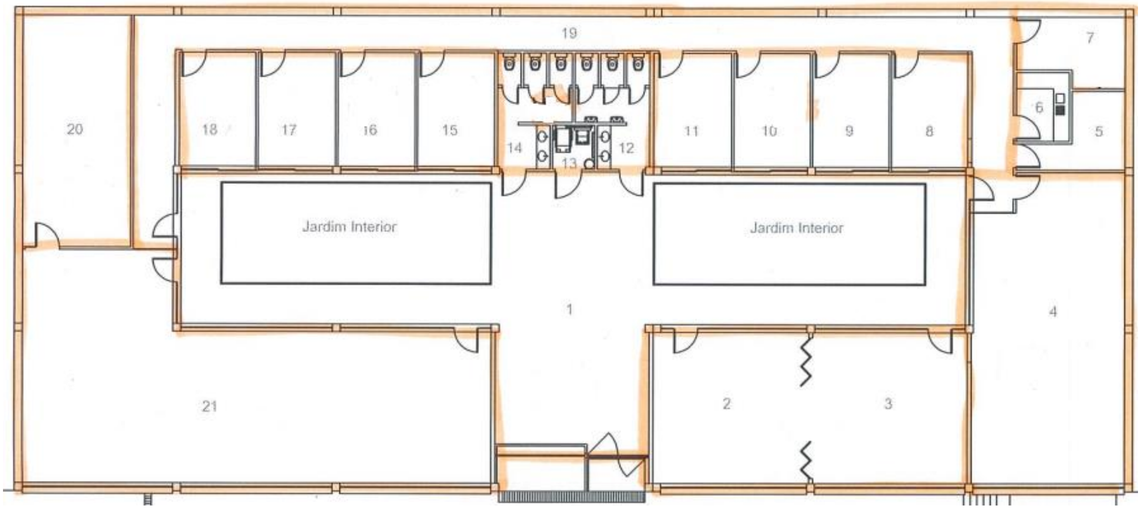

Figure 5.2-Floor Plan of Pavilhão de Informática II

Space Identification	Number on Floor Plan
Atrium	1
Meeting Room 1	2
Meeting Room 2	3
Multipurpose Room	4
Storage Room	5
Kitchenette	6
Technical Room	7
Office 8	8
Office 7	9
Office 6	19
Office 5	11
Male Toilet	12
Accessible Toilet	13
Female Toilet	14
Office 4	15
Office 3	16
Office 2	17
Office 1	18
Circulation Zone	19
Library	20
Library	21

Table 5.1- Floor Plan of Pavilhão de Informática II Space Identification

The total area of the building is 614 m^2.

The roof has two skylights, one with an area of 87,6 m^2 and another with 86,7 m^2. The skylights provide daylight and ventilation to the interior atrium. The roof of this building, Figure 5.3, has an available area of approximately 420 m^2 and the installation of photovoltaic panels set up wouldn't cause significant constraints to the landscape of the Campus.

Figure 5.3 - Roof of Pavilhão de Informática II

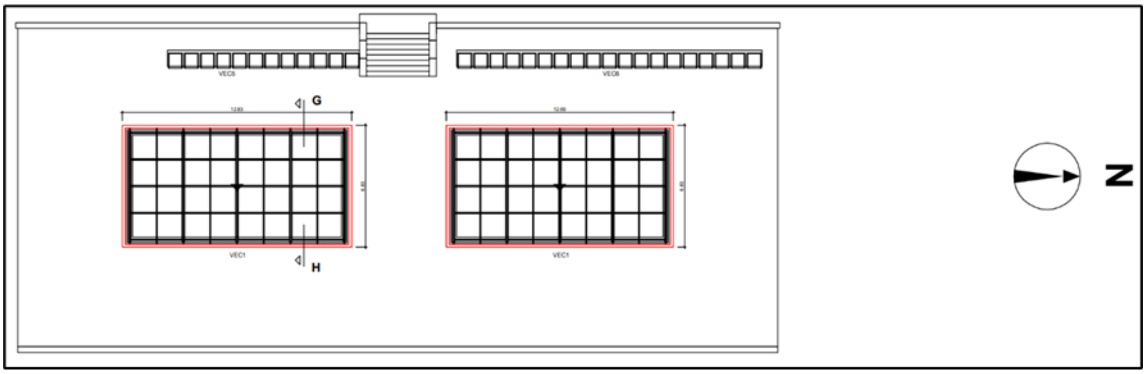

Figure 5.4- Roof plan and orientation of Pavilhão de Informática II

The building is under the responsibility of the Department of Computer Science and Engineering, and is mainly used by people of this Department, with the exception of the library that is open to all Técnico students.

5.1.2 Conversion to Net Zero

The intention of this practical case is to study the viability of the conversion of Pavilhão de Informática II into a building able to produce all the electrical energy it consumes.

The energy production is aimed to be made from converting solar energy into electrical energy by using photovoltaic (PV) panels. The excess of produced energy during the daylight period is stored in batteries to be used in the night-time.

The city of Lisbon has on average 255 days without rain, per year [68]. The solar radiation map developed by Lisboa e-nova suggests an average solar radiation of 1500 kWh/(m^2.yr) for the roof of Pavilhão de Informática II [69].

5.1.3 Data Collection

To start with the dimension of the PV system, a profile of the electrical energy consumption of the building was performed.

Due to the context of the COVID-19 pandemic that led to the campus occupation being abruptly reduced for the years of 2020 and 2021, it was decided to use consumption data relative to the last year before the pandemics, 2019. The EnergIST platform measures the energy consumption of all the Alameda Campus buildings, however, in 2019 the platform only measured the current intensity values. The current intensity values were measured in intervals of one hour and registered in EnergIST platform.

The energy consumption can be calculated with Equation 1.

$$C\,[A] \times V\,[V] \times PF \times \Delta t[h] = E\,[Wh] \quad (1)$$

The calculation of the energy requires data for the current intensity (C), the electrical tension [V], and the Power Factor (PF).

As the data of the power factor were unknown, it was necessary to calculate it. The determination of the power factor was made by solving equation 1 in order to the power factor. An iteration was made using current intensity and energy values from January 2021 to September 2021, as, the EnergIST platform was updated and now also measures the consumed energy. The electrical tension for this calculus was assumed to be 230 V. An average power factor of 0,852 was obtained.

With a known power factor, the hourly energy consumption for the year 2019 was calculated.

To identify the most critical months and posteriorly dimension the PV system, a profile of the solar irradiance was required. For this purpose, a Photovoltaic Geographical Information System from the European Commission was used [70], Figure 5.5.

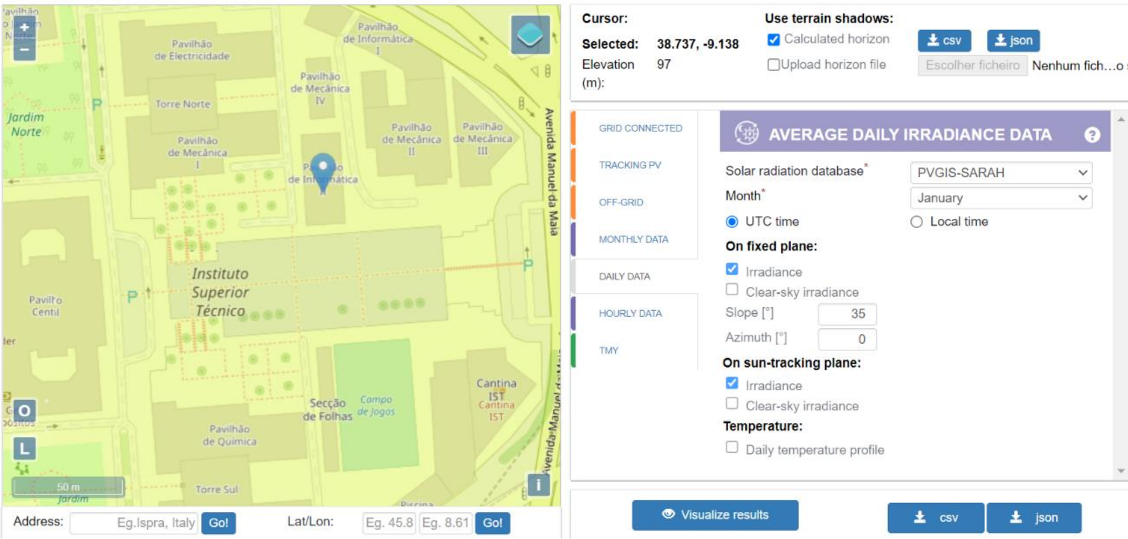

Figure 5.5- Photovoltaic Geographical Information System

The software calculates the daily average radiance for a chosen location and month of the year. The calculations used the default database, PVGIS-SARAH, and a slope of 35°, as this was the software default value for every month of the year, and the software produced the results for the selected data, Figure 5.6.

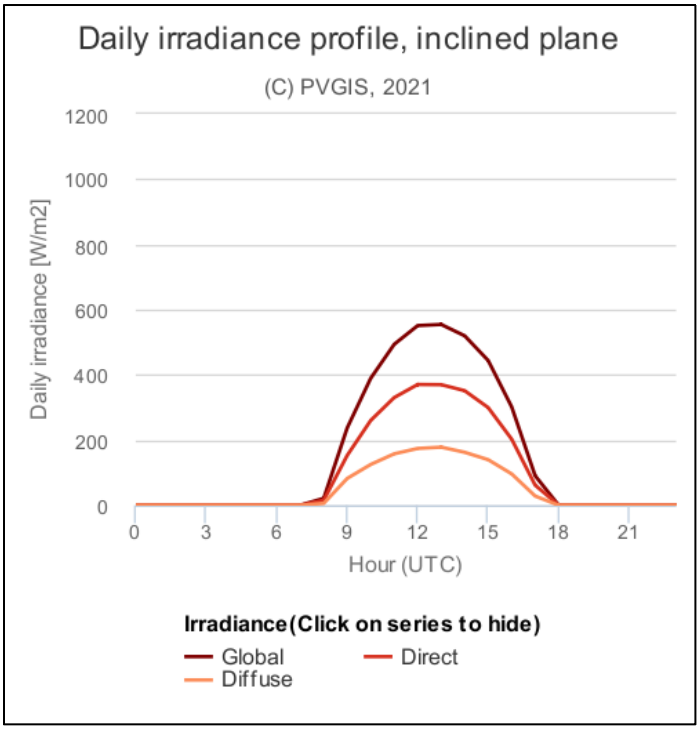

Figure 5.6- Daily irradiance profile obtained for January.

This methodology was followed for every month of the year to identify the month with the lowest daily irradiance profile.

The months of January and December are typically the months with the lowest profile of average daily radiance. In addition, during these two months, the electrical energy consumptions are between the highest values, along with July and September, see Table 5.2. As July and September have considerably higher solar irradiance profiles, the dimension of the PV system is made for January and December.

Month	Total Consumption [KWh]
1	2367
2	2170
3	2334
4	2223
5	2461
6	2322
7	2553
8	2290
9	2542
10	2396
11	2289
12	2429

Table 5.2- Pavilhão Informática II monthly electrical energy consumption in 2019.

The average daily solar irradiance profiles for December and January were then compared to the energy consumption profile of the days that registered a higher energy consumption for January and December 2019, Table 5.3. The days were the 23^{rd}January 2019 and the 20^{th}December 2019, with a total energy consumption of 82908,7 Wh and 82943,0 Wh, respectively. This decision guarantees a conservative sizing of the PV system.

	January		December	
Hour	Consumed Energy [Wh]	Solar Irradiance [W/m^2]	Consumed Energy [Wh]	Solar Irradiance [W/m^2]
1	2977,4	0	3302,5	0
2	2999,4	0	3293,3	0
3	3017,2	0	3268,4	0
4	3007,2	0	3372,3	0
5	3010,1	0	3560,2	0
6	2996,0	0	3362,5	0
7	2975,1	0	3221,2	0
8	3077,7	19,48	3252,5	37,73
9	3641,7	225,12	3307,8	251,62
10	4482,0	373,2	3478,5	392,57
11	3988,2	475,64	3672,9	502,91
12	4397,7	532,24	3734,8	548,87
13	4228,8	535,63	3569,0	543,85
14	3991,7	500,84	3928,8	485,71
15	3989,7	425,62	3661,3	379,99
16	3892,2	286,17	4054,6	229,09
17	3748,7	83,76	3828,9	1,46
18	3640,2	0	3939,6	0
19	3346,0	0	3786,9	0
20	3386,2	0	3271,7	0
21	3149,3	0	3108,1	0
22	2982,5	0	2978,2	0
23	2989,0	0	2983,7	0
24	2994,7	0	3005,2	0
total	82908,7	3457,7 [Wh/m^2]	82943,0	3373,8 [Wh/m^2]

Table 5.3- Daily solar irradiance and electrical energy consumption for January and December.

5.1.4 PV System sizing

Having a profile for the daily solar irradiance it was necessary to size the PV system to satisfy the energy needs. The electrical energy, E, converted by a PV system was determined with Equation 2, where Δt represents a time interval, η is the efficiency of the PV system, A is the area of PV panels, and G the solar irradiance.

$$E[Wh] = \Delta t[h] \times \eta[\%] \times A[\mathrm{m}^2] \times G[\mathrm{W/m}^2] \quad (2)$$

The energy needs were known from the energy consumption profile, thus it was possible to solve Equation 2 to obtain the area that meets the required energy, leading to Equation 3. The time interval considered was one hour, since the consumed energy and solar irradiance values were measured in intervals of one hour. The efficiency was obtained from the datasheet of the considered Photovoltaic module, LG NeON2 – 350W [71], and is equal to 20,3%.

$$A = \sum_{i=1}^{24} \frac{E_i}{\Delta t \times \eta \times G_i} \quad (3)$$

Solving Equation 3 for $i = 1$ to $i = 24$, the areas represented in Table 5.4 are obtained.

	January	December
Area $[\mathrm{m}^2]$	119,9	122,9

Table 5.4 - Required areas calculated for January and December

The same methodology was repeated for every month of the year. The following profile of areas was obtained for each month of the year, regarding the consumptions of 2019, Figure 5.7.

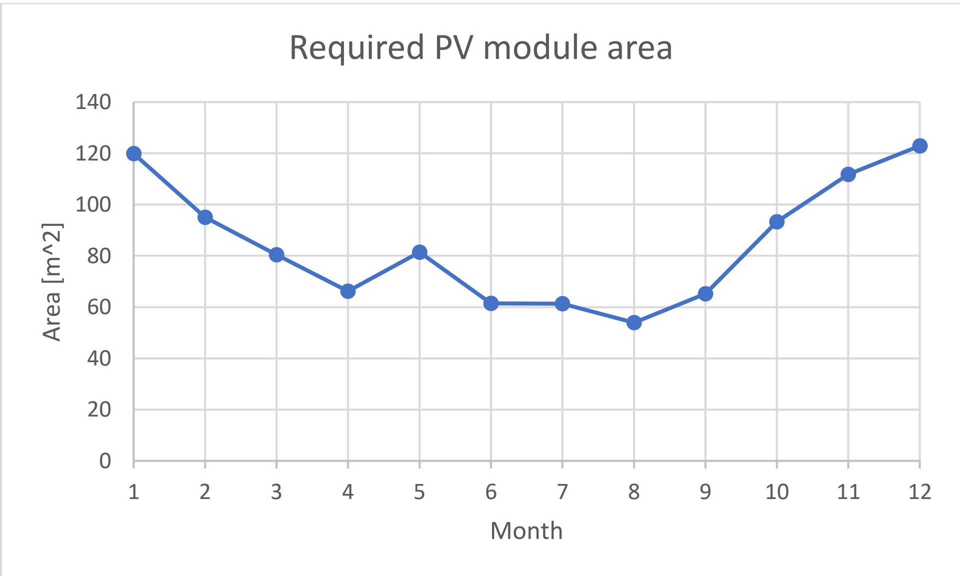

Figure 5.7- Required PV area for each month of the year

The results confirm that January and December are the critical months.

When representing the daily profiles of energy consumption and energy production graphically for the determined area, the results expressed in Figures 5.8 and 5.9 are obtained.

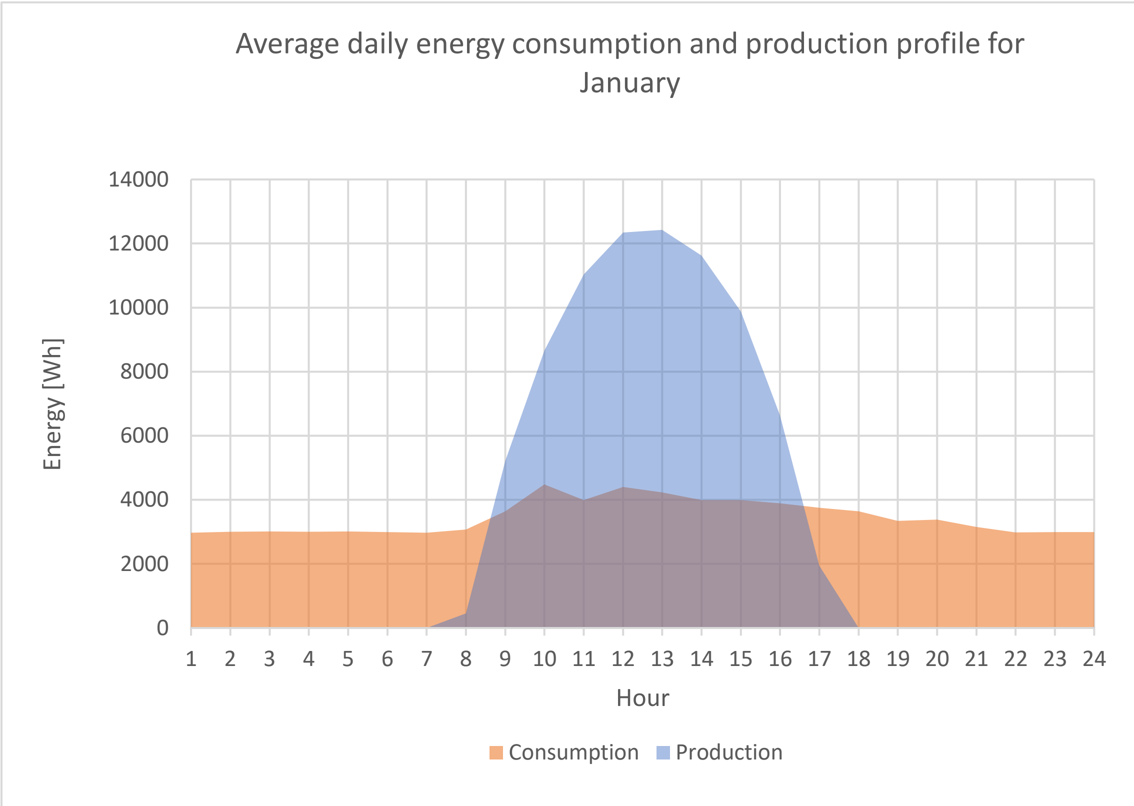

Figure 5.8- Average daily energy consumption and production profiles for January

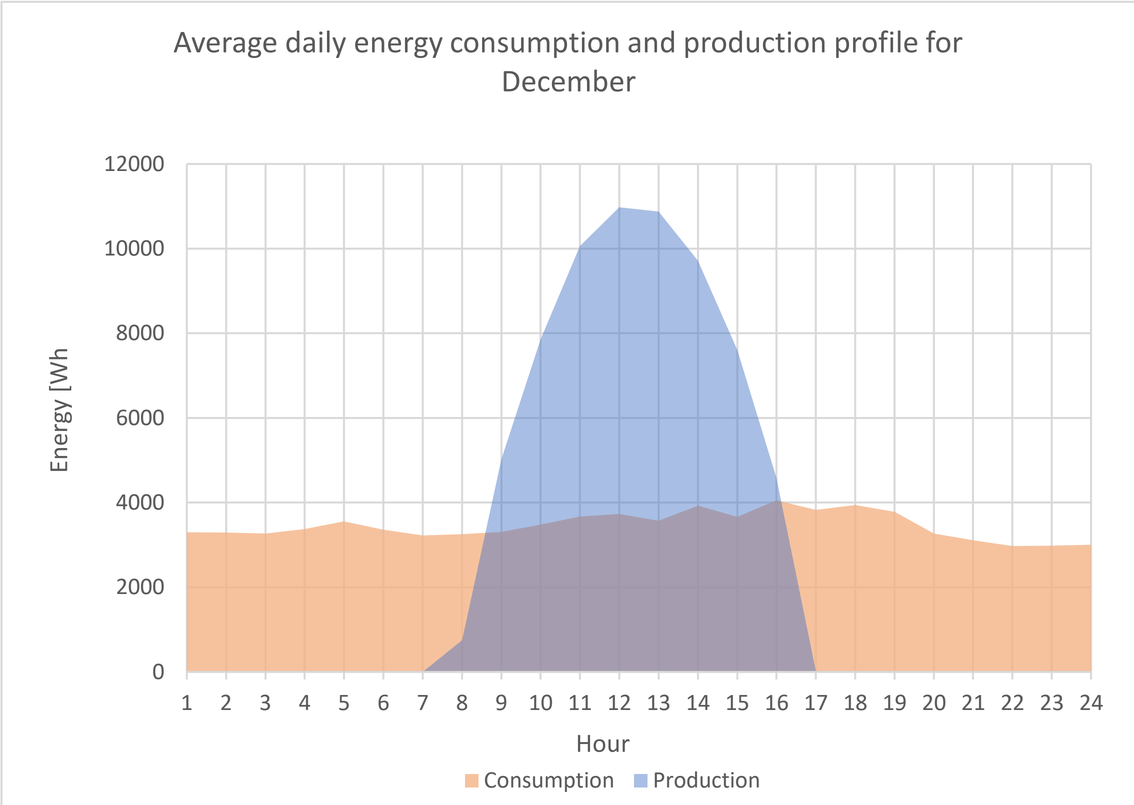

Figure 5.9- Average daily energy consumption and production profiles for December

Figures 5.8 and 5.9 indicate that approximately between 8h30 and 16h30 the PV system is producing more energy than required. The excess must be stored in batteries that will supply energy when the PV system is not producing energy, Figure 5.10.

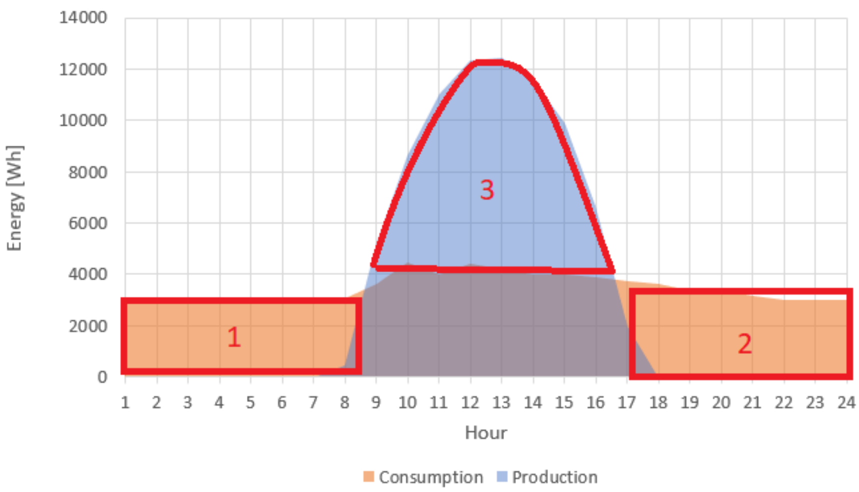

Figure 5.10- Energy balance scheme

A photovoltaic module area of 119,9m^2 for January and 122,9 $\mathrm{m}^2$for December are the minimum areas, that guarantee that the energy production covers the energetical needs, which means that the area 3 represented in figure 5.9 is equal to the sum of areas 1 and 2. The area of the considered PV module is $1{,}73\text{m}^2$. Dividing the total required are by the area of each module, the number of required PV modules is obtained, which is 71 modules.

The battery capacity corresponds to the sum of areas 1 and 2, which in this case, for the critical month, December, is 52,6 kWh.

5.1.5 – Financial analysis

To perform the financial analysis, it was assumed that the electricity has a cost of 0,14€/kWh. Each PV module costs 300€ [72], the battery cost was estimated, from prices available in specialized stores, to be 500€/kWh [73][74], a cost of 15% of the battery cost was considered for the battery management system and the inverter [75]. This represents a total investment of 51 545 €. The results of the investment are represented in Table 5.5 and figure 5.11, which suggest a pay-back time of 18,31 years.

Year		0	1	2		18	19	20
Investment		-51545						
Cash-Flow		-51545	3972,4	3972,4		3972,4	3972,4	3972,4
Actual Cash-Flow		-51545	3819,6	3672,7		1960,9	1885,5	1813,0
Accumulated Cash-Flow		-51545	-47725,4	-44052,7	…	-1257,1	628,4	2441,4
Discount Rate	4%							
Net Present Value [€]	2441							
IRR	13%							

Table 5.5- Financial Analysis of the Investment

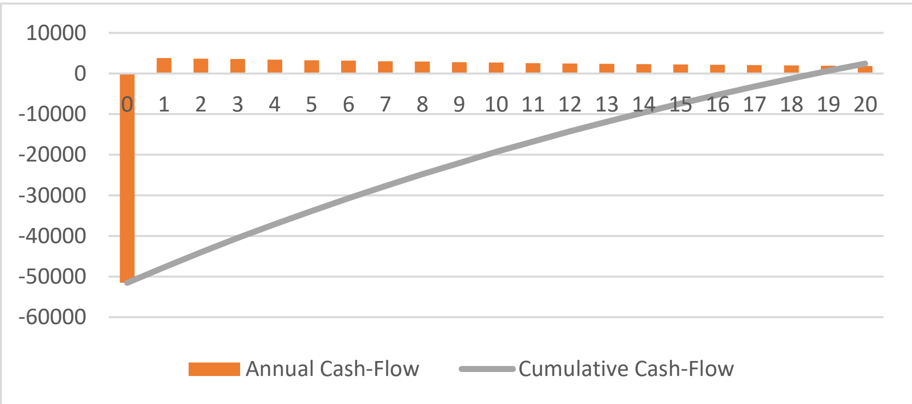

Figure 5.11- Pay-Back Period

5.1.6 – Living Lab Characterization and Conclusions

The Table 4.2 suggested for Living Lab presentation in "4.2.3 Living Lab Characterization" can now be used for this case study, as expressed in Table 5.6.

		Dimension Definition
Dimensions of the Living Lab	**Theme**	Energy Conversion – Solar Energy to Electrical Energy.
	Personnel	Drafted by a student, no working group yet.
	Technologies	This Living Lab as designed so far only makes use of technology related to the PV System. There is a possibility to include an Energy Management System and related technology.
	Infrastructure	This Living Lab requires the installation of a full PV system, composed by Photovoltaic Panels, Inverters, Charge Controllers and Batteries.
	UN Goals	This Living Lab is related to UN SGD goals 7 – Renewable Energy, 9 – Innovation and Infrastructure, 12 – Responsible Consumption and 13 – Climate Action.
	Funds	The required budget to implement this Living Lab is 51 545€.
	Partnerships	No partnerships were made yet. The Living Lab could eventually partner with partners specialized either in Renewable Energy or Energy Management System and associated services and technologies.
	Outcomes	Set a model of a Net Zero Building in Campus, leading the way to carbon neutrality.

Table 5.6- Characterization of the Net Zero Building Living Lab

The life expectancy for lithium batteries varies from 5 to 15 years. The retailer for the considered models indicates a lifespan of 6000 cycles [73][74]. Considering approximately one battery cycle per day and optimal storage and operating conditions, the lifespan would be close to 15 years. This implies that the best scenario for the duration of the battery is shorter than the payback time of the investment, meaning that, as designed, this investment is non-viable. However, the manufacturer of the considered photovoltaic module indicates a life expectancy of up to 25 years for that product [71], which leads to the possibility of developing an alternate solution for this Living Lab. Either a solution with an Energy Management System, to lower and optimize the consumptions and thus minimize the required battery capacity, or a solution with a different type of batteries. A partnership with an industry entity specialized in battery development could also be a solution, as this Living Lab could be used to test new battery solutions while simultaneously sponsor the Net Zero Building.

6. Conclusions

The analysis performed for this thesis revealed that the involvement of Universities in sustainability related activities differs from institution to institution. The budget of the universities was also revealed to be related to the amount and type of initiatives being developed. The creation of funds, courses, grants, and research stimulation can be seen as a tool to bridge the gap between a traditional Top-Down approach, where the activities to be developed are designed by the governance, and a Bottom-Up approach, that incentives students, researchers, professors, and staff members to develop and take part in interventions for a campus even more responsible in resources utilization.

At Técnico Alameda the energy sustainability related activities are mainly developed by the Energy Initiative, which is also responsible for the creation of the CALL. One of the intentions of creating the CALL is to provide the conditions to complete Técnico's approach to sustainability with the Bottom-Up approach. The work developed for that purpose involved a contextualization of the Alameda Campus, either in the equipment, infrastructures and energy consumption data that is available to study and develop activities, or in the interventions regarding especially electrical energy consumption and water-use that were made so far in the context of the Sustainable Campus Project.

Designing the CALL and presenting it to the community via website and email resulted in the obtention of Living Lab ideas, mainly from students and researchers. The collaboration between these students and researchers and the professors involved in the design of the CALL as a multi-layer platform (in "4.2.2 The CALL as a Multi-Layer Platform") allows combining younger members of the community, that often come up with new and creative solutions, with experienced professors that entail plenty of experience and know-how on various subjects.

The developed strategies led to setting a governance structure for the CALL that can maximize its potential by being as inclusive as possible and by working in collaboration with the Technology Transfer Office, more specifically its Core for Corporate Partnership. This collaboration envisions a situation with mutual benefits. The CALL can rely on the Technology Transfer Office to find help in creating partnerships to support Living Labs, while the Technology Transfer Office can make use of the CALL to attract partners to Técnico Partners Network, presenting as a new dimension in the partnerships where the partners can research and test technologies and services in a real world scenario while contributing for a better Campus, as suggested in "4.3 Aligning ideas and financing sources – Promote industry-university relationships".

The case study regarding the conversion of Pavilhão de Informática II into a Net Zero Building resulted in a blueprint of what could be a Living Lab to be implemented. The presented solution revealed some limitations, especially regarding the sizing of the battery system to allow the building to operate when the photovoltaic system is not converting energy, resulting in the project possibly being financially non-viable. However, an alternative approach to this Living Lab could result in significant improvements, which could be achieved with a collaboration with a partner interested in introducing an Energy Management System, to reduce and optimize energy consumption and thus minimize the required battery capacity, or in using this Living Lab to test alternate battery solutions, as battery development is nowadays an area of interest in the development of solutions for sustainable energy production, storage, and use.

Finally, it is possible to complete that future work must be done for the purpose of the CALL, starting by implementing the measures presented in this document. Certainly, there are other possible design suggestions for its development that could be explored to later be compared to the solution presented in this thesis. Such comparison would be relevant to trace the best strategy for the CALL development.

7. References

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A. Appendixes

Research Questions Tables For each Institution

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding
"Energia 2020" - Genoa University (Savona Campus)	Public University Project developed in the Savona Campus of Genoa University, one of the regional campus of the Genoa University. The Savona Campus has 2 300 students divided by 3 Schools.	No information	The Living Lab, the control centre that gives life to and manages this complex smart grid, has been financed entirely by public money as part of the University of Genoa's Energy 2020 project (8 million euros from the Ministry of the Environment, the Ministry of Education and the Liguria Regional Administration). [10]

Table A.1 - Research Questions Genoa University

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding
University of British Columbia (UBC) – Campus as a Living Lab (CLL)	Public Research University. 2 campuses with 66 512 students in total (55 161 undergraduate and 11 351 graduate) 16 faculties 18 schools	Types of partners: "5C's" Collaborations with 5 types of partners: Colleges and universities, Corporations, Community, Cities and Countries [12] Possibility to partner for research. 1,424 research projects with industry partners 1,243 research contracts and agreements with government and non-profits [11]	2 727M$ annual budget. $672.7 million in research funding for 9,941 projects [11]

Table A.2- Research Questions UBC

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding
Wageningen University and Research (WUR)	Public Research University 13 275 students 6 037 bachelor's students 6 939 master's students 2 183 PhD candidates studying. 1 faculty divided into 5 departments [13]	"Call for partners" WUR pursues cooperation with other organization for research in several areas. Presentation of the projects that are available for partnership. The partnerships are open to businesses, civic organizations or companies. [14]	Between 362 million € to 385 million € for last 3 years 55% comes from government funding, 11% from bilateral market, 10% from tuition fees, 9% from research funding and targeted subsidies, 5% from co-funding and matching market revenue, and 10% from other sources [15]

Table A.3- Research Questions WUR

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding (of UPM)
Universidad Politécnica de Madrid (UPM) – Alianza Shire	Public University 4 Campus 18 Schools/Faculties 17 Research and Development Centres Over 35 738 bachelor and masters programmes students, 1 900 doctoral students. 200 research groups 71 Industry-University Endowed Chairs [17]	Industry-University Chairs: mean to establish a strategic and long-term partnership between companies/institutions and the University in order to carry out education, research or knowledge transfer activities in an area of common interest. Two types of units have been established: Industry-University Chair and Aulas. The differences between the two are that the Chairs require their own facilities while the aulas can use facilities of the school. The Chairs and the Aulas imply a minimum financial contribution of 30 000 €/yr and 10 000 €/yr respectively. [16]	Total Budget 320,8M€ Tuition and Fees 91,5M€ Public Financing 213,5M€ Private Financing 4,05M€ International Funding 11,6M€ Research: 19,1M€ Public National Funding 3,7M€ Contracts w/ Private Industry [17]

Table A.4- Research Questions UPM

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding
Harvard University	Private Research University 12 Graduate and Professional Schools plus Harvard Radcliffe Institute 31 566 students* 9 950 Undergraduate and 21 616 Graduate 21 006 Full-time and 10560 Part-time *Academic year 2018-19 [18]	Each School makes partnerships with entities regarding the area of research/teaching. The Office of Technology Development works to connect innovators with industry. The partnerships are made to benefit each part. To the faculty and Inventor: advance the research, protect intellectual property and execute a business development strategy. To the Industry and Inventor: gain access, license technologies and catalyse a start-up. [19]	Operating Revenue 2020: 5 400M€ Sources of operating revenue: 37% Endowment 17% Education/tuition 17% Research 9% Gifts 20% Other [20]

Table A.5- Research Questions Harvard University

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding
MIT	Private Research University 1 Urban Campus 5 Schools and 1 College 11 520 Students 4 530 Undergraduates 6 990 Graduate [21]	Currently over 700 companies are working with faculty and students on projects of mutual interest. MIT Corporate Relations aids and directs companies interested in multidisciplinary involvement with the Institute, with 2 programs: The Industrial Liaison Program is instrumental in providing connections to MIT faculty, departments, labs, and centres. It serves companies across the globe and is organized both geographically and by industry. MIT Start-up Exchange actively promotes collaboration and partnerships between MIT-connected start-ups and industry. Qualified start-ups are those founded and/or led by MIT faculty, staff, or alumni, or are based on MIT-licensed technology. [22]	Total Operating Revenues: 3 932M€ Revenue sources: Research – Lincoln Laboratory 27% Investment Return 22% Research – Campus 19% Gifts 10% Tuition 10% Other operation 8% Auxiliary enterprises 3% Research – Singapore MIT alliance 1% [23]

Table A.6- Research Questions MIT

Institution/Project	Type of University	Partnership Mechanisms	Budget/Funding
TU Delft	Public University 8 Faculties 26480 Students 13 806 Bachelor's students 12 435 Masters' students 2 921 PhD Students [24]	"Business Friend": Minimum donation of 2 500€/yr for 3 years to be part of a network of businesses that are closely involved with TU Delft. This guarantees the benefits of attending major events at TU Delft, subscribe the "Friends Newsletter" and publicity. "Good Friend": Minimum donation of 500€/yr for 5 years (or 1 single donation of 2 500€) to be part of a network of committed alumni and other associates of TU Delft. This guarantees the benefits of attending major events at TU Delft, attend a masterclass (twice a year), subscribe the digital "Friends Newsletter" and be credited in the Delft University Fund annual report and on the Good Friends webpage. There is a possibility to support research projects that are listed on TU Delft website. "Your Named Fund": A Named Fund can be established by making a donation via notarial deed or by including the Delft University Fund in an investment of at least € 50,000 in a single instalment or five annual instalments. The donor can determine what is done with its assets and discuss his wishes with TU Delft in detail. TU Delft also partners with associations, industrial partners and academic partners. [25][26][27]	Total Income (2019): 762M€ Government and other contributions: 439M € Projects with third parties: 216M € Tuition and examination fees: 73M € Other: 34M € Total Expenditure (2019): 719M € Depreciation: 38M € Other: 177M € Personnel: 504M € [28]

Table A.7- Research Questions TU Delft

Living Lab/Project characterization Tables for each institution

	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/Achievements	Projects
"Energia 2020" (Genoa University)	Does not identifies as a LL	Managed by University Service Centre (entity responsible for the activities in Savona Campus) Research activities performed by Power System Research team of University of Genoa – team of aprox. 10 researchers and technicians. [31]	Set an example on how to build a Smart sustainable city Conduct research and innovation on smart energy buildings, energy management systems and microgrids. Exchange of information, ideas, and best practices for achieving sustainable campus operations and integrating sustainability in research and teaching. [29]	public partnership with national and local authorities to fund four projects.	Italian Ministry for the Environment and protection of Land and Sea (2,7M€) Italian Ministry of Education, University and Research (2,4M€) Liguria Region (1,5M€) [31]	"Energia 2020" project has been cited on the International Sustainable Campus Network (ISCN) website regarding innovation and sustainability themes. The Campus as a "test-bed" of state-of-the-art technologies for the City of the Future (digital City iper-connected, City secure, health & wellness for the Citizens) Serve as example of a sustainable building. U-Gym available in the Campus Living Lab to test electrical appliances [31]	SEB (Smart Energy Building): construction of a nearly Zero Emission Building connected to SPM SPM (Smart Polygeneration Microgrid): implementation of a smart microgrid to provide electrical and thermal energy. EEM (Energy Efficiency Measures): upgrading the energy efficiency of existing Campus Buildings. Smart City Demo Campus: transform the Campus in a Smart Urban District of the Future, installing new technologies in ICT, energy and environment sectors in order to show a real implementation of the Smart City concept to population and external stakeholders. [29]

Table A.8- Living Lab/Project characterization Genoa University

	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/ Achievements	Projects
University of British Columbia (UBC) – Campus as a Living Lab (CLL)	"physical spaces and human systems in which we design, test, study, and learn from social and technical innovations in real time and real world contexts. They support collaborative experimentation, piloting of innovations, critical assessment of results, and exchange of knowledge". [33]	The CLL activities are managed by the Sustainability Initiative that includes various committees and working groups, involving dozens of individuals (academics, board representative member, student advisory members, various managerial staff) with direct report between them. [34]	Respond to challenges as climate emergency, ecosystem destruction, global urban migration, pandemics and economic change by integrating academic research and teaching with campus planning, infrastructure, operations and community development. Use the UBC Campuses as a testbed for the potential commercialization of products that can help with campus sustainability [33]	The projects are developed either by solicited proposal (Top-down) or by unsolicited proposal (Bottom-up). The solicited proposal projects are issued by the governance with a defined action-plan and funding. The unsolicited proposal projects start with the submission of the proposal, that later is reviewed by the different working groups and committees to evaluate it and eventually fund it. [34]	"5c's" partnership [12] Companies and NGO's. The UBC is interested in partnerships with industrial and community partners. For that, UBC issued a request for information to develop strategic partnerships with industry in 2011, resulting in an increasing number of companies approaching UBC to collaborate. [34]	CIRS: "living lab" with ongoing performance monitoring and activities to further improve Performance. Academic District Energy System - o convert the campus district heating system from steam to hot water, saving 5,5M C$/yr and 22% reduction in GHG emissions. Bioenergy Research and Demonstration Facility – use renewable resource for fuel allowing to reduce GHG emissions by 9 000 ton/yr [34]	Centre for Interactive Research on Sustainability (CIRS), as a LL and a "net-positive energy producer and net-zero carbon building" Academic District Energy System - convert the heating system of 131 buildings across the campus from steam to hot water Bioenergy Research and Demonstration Facility - to reduce imported power on campus by using a renewable source for fuel [34]

Table A.9- Living Lab/Project characterization UBC

	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/Achievements	Projects
Wageningen University and Research	"Living Labs are a good way to test, create and develop metropolitan solutions with impact. It makes a connection between fundamental research and the step to a society-wide implementation" [35]	The LL are developed by the students of MSc Metropolitan Analysis, Design and Engineering (MADE). Each LL is governed by MADE students. MSc MADE is a collaboration between Wageningen University and Research, Delft University of Technology and AMS Institute.	"Solutions for a wide range of urban challenges. " "Make impact by developing new products on a small scale – be it an object, a service, a technology, an application, or a system – and to find solutions that can be implemented on a larger scale." [36]	Creation of MSc MADE to develop research around 6 urban challenges: Smart Urban Mobility, Urban Energy, Climate Resilient Cities, Metropolitan Food Systems, Responsible Urban Digitization, Circularity in Urban Regions. This will give the students skills to develop and manage a LL. For that, "The first academic year consists of courses such as Metropolitan Challenges, Data and Entrepreneurship. These will prepare you for the Living Lab in the second year. The Living Lab approach will enable you to work on real-life cases within the city of Amsterdam". [37]	Knowledge Institutes (AMS Institute and Delft TU) – partnerships made by the administration of the MSc MADE. The students are allowed to develop partnerships with Private and Public entities to support their LL.	Involve Msc MADE students in Living Labs, collaborating with AMS Institute and other entities, leading to the creation of new Living Labs every year.	Living lab DGTL - Illuminating NDSM: students developed movable light objects that can be used as atmospheric lighting during DGTL festival and for street illumination in a dark area off the city where many streetlights are broken. WASCOM - urban waste to urban material: develop a product with an urban application from a new material (WASCOM) developed out of waste water flows from the city, resulting in a flower planter. Concretely circular - Concrete is one of the largest waste streams and the most of its waste in the Netherlands is "downcycled" and used as foundation for roads and infrastructure. This project aims to recycle concrete to produce products with higher value, upgrading the value of the concrete in the value chain. [38]

Table A.10- Living Lab/Project characterization WUR

	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/Achievements	Projects
Universidad Politécnica de Madrid – Alianza Shire	Does not identifies as a LL – this activity is not a University LL, despite applying some LL principles.	Composed by 3 Management bodies: Steering Committee – composed by managers from each partner entity, working at the strategic level of the partnerships and is in guidance of the partnership and its initiatives and projects. Technical Team – composed by experts on energy from each partner entity with the purpose of providing support to other groups. Communication Committee – composed by one member of each partner with the function of managing the Partnership Internal communication, develop communication protocols and planning internal and external communication. Responsible for organization of information to allow efficient knowledge management. [39]	Develop energy supply solutions that improve services, quality of life and security in refugee camps.	The Partnerships are established to plan, fund and perform the activities. There is a technical formation of a group of refugees (involvement of the community), this will allow them to participate in the installation and recovery process and to perform the maintenance.	Universidad Politécnica de Madrid plays the role of facilitator and promoter, being responsible for the design and the management of a space for collaboration and to monitor the working process. Spanish Agency for International Development Cooperation and UN High Commissioner for Refugees are organizations that ensure institutional support and a wider knowledge of the humanitarian context. Norwegian Refugee Council is a NGO operating with the purpose of promoting and safeguarding the rights of displaced people. ACCIONA Microenergia Foundation, Iberdrola, Philips are the 3 leading private companies in the energy sector and provide technical knowledge on models for energy service provision, innovation, renewable energy, lighting and business model. [39]	Safer camps Firewood reduction of aprox. 1 500 ton/yr CO_2 emissions reduced by 2 000 ton/ry Savings in diesel consumption of 30 000€/yr Technical formation of members of the local community and toolkit donations. [39]	Adi-Harush refugee camp

Table A.11- Living Lab/Project characterization UPM

	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/Achievements	Projects
Harvard University	No definition	Office for Sustainability (OFS) manages the activities, which are organized in 5 topics: Emissions and Energy Campus Operation Nature and Ecosystems Health and Well-Being Culture and Learning [40]	Reduction of GHG emissions Reduce Waste Reduce Water use 75% of Organic Landscape [42]	The strategy consists of 6 main tasks: Campus Services and Central Administration start by Benchmarking Working Groups to provide baseline reports on current efforts and drafted goals, strategies and opportunities for improvement. Faculty, Student and School are Engaged to provide an insight and comment on the draft goals. OFS Drafts Plan with goals, standards and commitments all based on Student, faculty and staff feedback. Review Committee, composed of senior-level School Operation leaders, Central Administration departments and students assess the draft plan to identify implementation barriers or School-specific concerns and thus make specific recommendations on the proposed goals. All Community Meeting with facility leaders, Green Teams, Strategic Procurement, Human Resources and other stakeholders. Finally, the School Review and Sign Off is made by individual meetings with each School and Central Administration department leadership to review and sign off the final draft of the Plan. [43]	Boston Green Ribbon Commission Cambridge Community Compact for a Sustainable Future EcoAmerica MomentUS Initiative International Sustainable Campus Network [41]	Creation of Harvard University's first Sustainability Plan "Green Harvard" – Online Dashboard [42]	Campus Sustainability Innovation Fund Climate Solutions Living Lab Course and Research Student Grants

Table A.12- Living Lab/Project characterization Harvard University

	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/Achievements	Projects
MIT	"Rigorous campus-based research with operational, academic partners, sustainable data collection/analysis, formal and informal learning activities and measurable outcomes [44]	The Office of Sustainability is promoting 5 initiatives: Zero-Carbon Campus: activities regarding Climate, Buildings, Energy and Mobility Climate Resilience: activities regarding Planning, Climate Risks, Education and Resilient Ecosystems Material Life-Cycle: activities regarding Procurement, Waste and Re-use Healthy People: activities regarding Food and Environmental Justice. [45]	Solve global sustainability issues at a local level	The LL follows 4 different processes Research Process: linear and non-linear sequencing of research questions, literature review, design methodology, data collection/analysis Ideation Process: non-linear sequences such as intake/define, collaborate, digest, prototype, connect/reconnect, test/outcomes Filter Process: This includes a non-linear process by which strategic decisions about the prioritization of new work, or about the next steps of existing work Teaming Process: team launch, team build, team re-launch [44]	Campus: climate scientists, transportation experts, researchers, staff, and broader community working together to improve sustainability in Campus, through working groups, task forces and key events City: partnership with the Cities of Cambridge and Boston to work on urban solutions outside the Campus Global: work with entities around the world to find and exchange campus sustainability solutions [46]	Created grants Convened stakeholders Catalysed Competitions Launched Initiatives	Solving for Carbon Neutrality [47]

Table A.13- Living Lab/Project characterization MIT

	Definition of LL	Governance	Objectives	Strategy	Partnerships	Outreach/Achievements	Projects
TU Delft	“A Campus as Living Lab is the integrated organizational, technological and socio-economic approach in which a university uses its assets and facilities to investigate, test or demonstrate innovative technologies or services by, with and for their community” [5]	No detailed information	Learning as an integral element Involvement of Users Innovation as a goal	Define location Provide Context Design the process and task division Secure financial resources Prepare and approve legal and risk documents Reservation of finance for research (time, tools and reflection)	Research Community Student Community Operation Community Non-University Stakeholders	5 main outcomes: Research Education Campus Operation Community Connections w/ industry	Green Village

Table A.14- Living Lab/Project characterization TU Delft