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Solid Waste Management Approach at the University through Living Labs and Communication Strategies: Case Studies in Italy and Portugal

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Abstract: Universities are today seen as living labs for the creation of knowledge with the aim of transferring it to society. The integration of sustainability is a critical point in this context, as solutions for problems experienced in society can be experimented with regarding physical aspects, such as Solid Waste Management (SWM), and efficiency in energy and water use, but also social aspects such as accessibility, equality, and inclusion. This paper explores the implementation of similar SWM projects in two European universities, Milan-Bicocca University and Instituto Superior Técnico from Lisbon University. Milan-Bicocca was the pioneer project that followed an ambitious model that demanded the removal of all isolated waste bins from inside the offices and rooms, replacing them with waste collection islands in the public spaces. This meant a very coordinated procedure and communication plan, and inspired the pilot project in Instituto Superior Técnico, currently in the expansion phase. This paper describes the implementation of each model and their specificities, and a roadmap is proposed that resulted from the interactions, meetings, and discussions between the two teams, Italian and Portuguese.

Keywords: sustainability in HEI; solid waste management; HEI living lab; HEI sustainability project

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1. Introduction

Universities, that have been at the forefront of breakthrough developments for centuries, have mostly lingered with the same academic systems in terms of learning paradigms sustainability compromises towards society [1]. However, higher education institutions (HEIs) have been working significatively in the last three decades towards the integration of sustainability in their systems, with the need to move from simple technocratic and management efforts to address the so called "soft" issues including visions, philosophies, and employee empowerment becoming more clear [2]. In fact, higher education institutions are currently recognized as key actors of change in the transition towards carbon neutrality and sustainable societies, both greening their own footprint and contributing to their surrounding communities as responsible societal actors [3].

Today, environmental sustainability and greening are being handled by an increasing number of European universities as part of their institutional values, aimed at reaching the

Sustainable Development Goals (SDGs) of the United Nations and the European Union's Green Deal. This is highlighted by the report of the survey "Greening in European Higher Education Institutions", launched in September 2021 and conducted by the European University Association (EUA) involving nearly 400 universities [3]. These efforts were revealed through a large range of diverse measures and activities, such as addressing sustainability through education, research, and innovation, and the vast majority of institutions have at least some greening activities in place to physically green the campus. These can be either as part of a comprehensive approach by creating environmental management systems by addressing HEI as small cities [4], or at least with some activities. Although the implementation of practices towards green campus are one of the most direct actions towards sustainability in HEI, a review paper by Figueiró and Raufflet [5] shows that most papers address sustainability integration in general.

Solid Waste Management (SWM) is one of the ambits of campus greening and as a major society problem, must be not only implemented in the campus, but also discussed in research, teaching, and outreach activities [6], often proposing the use of the campuses as living labs [7–9]. Several researchers have addressed SWM within HEIs, often making a parallel with small municipalities. A study by Jibril et al. [10] states the 3Rs system (Reduce, Reuse, and Recycle) as a critical success factor for a sustainable SWM in HEIs. Zhang et al. [11] developed a study that identifies benefits, barriers, and practical and logistical problems in SWM in HEIs, illustrating them with a case study of the University of Southampton. This paper emphasizes the need for behavior change methods, as resistance to change has been a big challenge in sustainability projects in HEI contexts [12,13]. One of the critical points in the implementation of sustainable practices is related to students, a transient population in HEIs that is at the same time the major stakeholder group, especially regarding the adoption of recycling practices [14,15]. In fact, the need for especially targeted and carefully timed communications campaigns for these populations is one of the main conclusions of a study developed by Timlett and Williams [16]. An important aspect of research in HEI sustainability has been monitoring and assessment, with several authors proposing frameworks and indicators [6,17–19]. Most studies found in literature either investigate particular aspects of SWM models outside the context of HEIs or are focused on more general aspects of sustainability in HEIs. Still lacking is any study detailing the implementation of a SWM model in a HEI, describing not only the model but also the implications, limitations/barriers, and best practices.

In this paper, we analyze SWM at the HEI through the experience of living labs, and we present two case studies in two HEI with different levels of maturity regarding SWM, one in Bicocca (Milan, Italy), where the waste separation for recycling is fully implemented, and one in Instituto Superior Técnico (Lisbon, Portugal), where the first pilot project for waste separation was implemented in 2020. In 2015, the University of Milano-Bicocca successfully implemented an ambitious waste separation model that comprised the removal of waste bins from individual offices, rooms, and other spaces. This inspired the waste separation model implemented in 2020 in a Portuguese engineering school, Instituto Superior Técnico, as a pilot project in one building. Both teams, Italian and Portuguese, have been in contact and sharing experiences in the past 3 years, and in this paper, we share the implementation processes and the main results of each case study. Although the SWM model implemented is very similar, each HEI tried different methods for improving the involvement of the community, namely gamification methods, physical offers fostering more sustainable behaviors, active participation in decision-making, and finally a survey. The results were evaluated using Life Cycle Assessment (LCA) impact indicators, namely the climate change through CO_2 eq.

Finally, a roadmap is proposed for the implementation of the SWM followed by both universities, contributing to future implementations in other institutions with the main limitations/barriers and success factors found.

2. Case Studies

2.1. Milano-Bicocca Case Study—The Sustainability Project

The University of Milano-Bicocca has chosen to engage actively in order to make its structures, activities, and services sustainable from an environmental, social, and economic point of view. To do this, it has created the internal center BASE (Bicocca Ambiente Società Economia: Bicocca Environment Society Economy) [20]. The aim has been not only to reduce the costs and the environmental impact of its management but also to promote sustainable behavior among its employees and students and to pursue the UN Sustainable Development Goals. BASE proposes a holistic approach to sustainability that includes the commitment to energy, waste, mobility, climate change, water, food, and sustainability education. BASE works in cooperation with the University's Infrastructure and Communication Areas to harmonize the scientific and operational aspects. A peculiarity of BASE is that it addresses sustainability across the disciplinary areas of the university and its research, training, and management sectors.

Outside the University, BASE supports the attention towards sustainability by participating in working groups, locally (Bicocca district), nationally (RUS—Rete delle Università per lo Sviluppo Sostenibile, University Network for Sustainable Development) and at international level (ISCN—International Sustainable Campus Network).

Waste Management Model

As is well known, Directive 2008/98/EC of the European Parliament on waste, known as the Waste Framework Directive, aims to lay the basis for turning the EU into "a 'recycling society' seeking to avoid waste generation and to use waste as a resource". At the top of the waste management hierarchy is reduction, followed by reuse, recycling, and recovery. Final disposal is only foreseen at the end of this approach. The University of Milano-Bicocca internal waste management project was based on this same approach.

The implementation of the new urban waste management system was based on the placement of specific points in the corridors dedicated to separate collection and at the same time removing the waste containers from the offices. The project regarding the waste management at the University of Milano-Bicocca was called the "Fa la differenza!" (Make the difference!) project.

1st phase—Monitoring

For many years, the collection, management, and disposal of municipal waste within the University of Milano-Bicocca was addressed inefficiently and ineffectively and there was no standard method for managing the collection and disposal of waste across all the different buildings. Monitoring carried out during 2015 showed that 27% of that waste was being collected and disposed of differentially. Consequently, given that the amount of undifferentiated waste was an estimated about 330 tons per year, the environmental impact (in term of greenhouse gas emissions) of that waste disposing was very high: more than 100 tons of CO_2 eq/year. This value was calculated starting from the emission factors relating to the transport and combustion of waste at the Amsa incineration plant in Milan. In fact, due to the need for it to be transported to the waste-to-energy plant and incinerated, every ton of undifferentiated waste was responsible for producing 315 kg of CO_2.

2nd phase—Implementation

To reduce such a negative effect, a new waste management system was tested in 2016. First, all bins for undifferentiated waste were removed from all the offices and laboratories in the 28 university buildings and replaced with a paper waste collector only (as most of the waste is paper). Having studied the use of shared spaces in university buildings, approximately 500 "islands" for separate collection were installed at strategic points (corridors, study rooms, break areas), as illustrated in Figure 1.

Figure 1. Island for separate collection—University of Milano-Bicocca.

To comply with municipal standards, the containers on the "islands" were colored differently depending on the type of waste they were to contain (yellow for plastic and metal, white for paper, green for glass, and gray for undifferentiated waste, see the picture below), and these proved easy to identify and use.

An integral part of this new waste management system was "PolApp" (Figure 2), an application for smartphones and tablets that enabled users to monitor the "islands" and report back on the quantity and quality of differentiated waste that was being collected. Each "island" was identified by a QR code, making it possible for University users to detect and send information on how full the containers were, and whether there were any problems, which enabled them to keep the management of the system under control. It also enabled them to compile thematic maps of the quantity and quality of waste being produced in the various buildings of the university. PolApp served to stimulate the university community to correctly separate collection and to help monitor the situation (full bins, dirt, waste thrown in the wrong bins). Currently, the app is not used to manage the emptying of bins but only to sensitize users who can know where to throw waste correctly.

Figure 2. Use of PolApp, an application for smartphones and tablets that enabled users to monitor separate collection in university (in quantity and quality). A QR code on each island making it possible to detect and send information.

A parallel action of this new waste management system was aimed at reducing the need to collect and dispose of the plastic water bottles dispensed from machines or sold in university cafeterias and bars. For that purpose, 13 water dispensers were installed in the university buildings, and every year they have supplied, free of charge, approximately 253,000 L of natural and sparkling drinking water (enabling a saving of about 18,200 kg of CO_2 emissions per year). Finally, the free distribution of steel bottles (about 12,000 bottles), marked with the BASE logo, to the university students and staff has achieved the twofold result of limiting the use of plastic bottles whilst at the same time identifying these ecological flasks as the symbol of this new community of environmentally sustainable and responsible consumers.

This project was accompanied by the slogan "Fa la differenza!"—Make the difference!", playing with the word "difference" which refers both to separate collection (in Italian "raccolta differenziata") and to getting involved by people: "Bicocca wants to make the difference, make the difference with us!". This is based on the idea that each and every person can help achieve the University's sustainability goals with a simple gesture such as making proper separate collection.

3rd Phase—Evaluation

The implementation of the project was also monitored in order to evaluate it. As a consequence of the project, the rate of separate waste collection increased from 27% to 70% (of which 50% was paper, 16% plastic and metal, and 4% glass), with a reduction of 45% in greenhouse gas emissions. Regarding the parallel action to reduce the use of plastic bottles, this approach brought many other benefits for the community, namely the enhancement of the water resource, education on consumption, and the active participation of students and staff.

The main results achieved with the implementation of "Fa la differenza!" project were:

- 500 "islands" for separate collection at strategic points of shared spaces (corridors, study rooms).
- Separate collection increased from 27% to 70%
- 50% paper, 16% plastic and metal, 4% glass
- −45%: greenhouse gas emissions reduction.

2.2. Instituto Superior Técnico's Case Study—The Pilot Project "Mecânica I Faz A Diferença"

"Mecânica I Faz a Diferença" (MFD) was an initiative inspired by the Milano-Bicocca case, carried out by Técnico Sustentável, a project aimed at leading the perspective of environmental, social, and economic sustainability of Instituto Superior Técnico's institutional mission, in the Pavilhão de Mecânica I building at IST Alameda Campus, in Lisbon, between November 2019 and March 2020.

The main goal of this pilot project was introducing and monitoring a procedure of differentiated collection of MSW and the development of a model with operational management assessment practices and communication strategies. The project took place in a building that hosts several research centers, a library, a study room, and a lecture hall, with a permanent population of 100 people and a rotational population of 50 people. The project was carried out in four phases.

1st phase—Monitoring

In November 2019, the monitoring of the waste generated in the building took place, with daily weighing and volumetric and qualitative estimates of the undifferentiated residues produced in the building, where around 100 bins were installed in offices and rooms. This phase had the support of staff, researchers, and students. As expected, results showed almost an inexistent separation of waste, as illustrated in Figure 3.

2nd phase—Development of the Model MFD

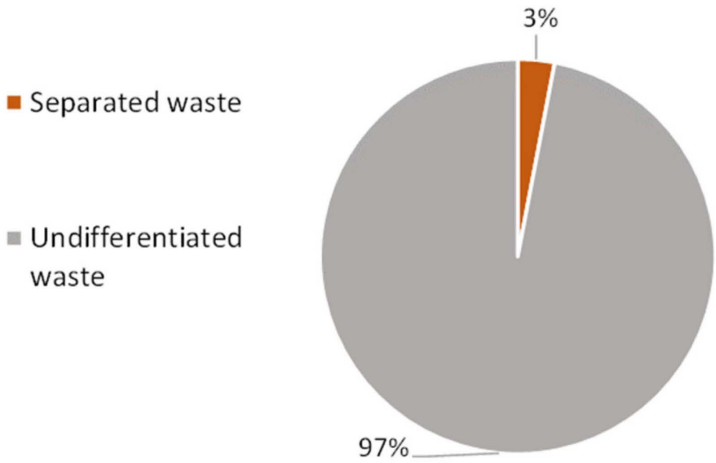

Figure 3. Waste monitoring process and results before the project implementation.

The model developed was based on the monitoring phase and according to the characteristics of the space under analysis with the following measures: (i) deactivation of all the undifferentiated waste bins in offices and rooms, (ii) placement of waste separation islands consisting of a set of bins (undifferentiated, plastic and metal, paper and cardboard, and glass) in strategic points in the common areas of the of the building (Figure 4); the bins were 100 L cardboard bins suit for residues collection; (iii) changing the collection frequency, the collection of undifferentiated residues and organic residues becoming daily, and the collection of plastic residues, glass, and paper/cardboard residues becoming weekly; (iv) since there was a significant amount of organic residues in the total waste generated in the building, it was decided to adopt the use of small buckets in some of the islands to allow the separation of compostable organic residues; (vi) a compost bin provided by Câmara Municipal de Lisboa's program "Lisboa a Compostar" was placed in the building's garden (Figure 5). This phase also involved a Communication Plan composed of numerous integrated measures.

Figure 4. Island for separate collection—Instituto Superior Técnico (ULisboa). **Legend:** Indiferenciado—Undifferentiated; Plástico/Metal—Plastic/Metal; Papel e Cartão—Paper and cardboard; Vidro—Glass.

(**a**) (**b**)

Figure 5. (**a**) The compost bin placed in the building's garden; (**b**) buckets for compostable organic residues.

The project was developed to ensure a proper communication plan that would not only inform users of the new SWM procedure, but would also involve the whole community in the process. For that, several steps were taken prior to the implementation.

In the preparation phase, an online survey was developed to characterize the behavior and pro-environment attitudes of the users in the building of the pilot project. This survey, called Sustainable Habits in the Work Environment, was based on a survey developed and applied in Wageningen University [21]. This survey also served as a communication channel to increase the awareness of the school community for environmental sustainability aspects, and ultimately to maximize the success of the pilot project.

A team was formed to design, implement, and monitor the process, and was composed by the project coordinators, the building manager, and the cleaning staff and their coordinator (Figure 6). This team had an active participation in decision making and was responsible for (i) defining the number of islands in the building and their location based on the needs and characteristics of the users, (ii) developing clarification sessions with the offices of all research centers/libraries/groups in the building, and workshops to inform all cleaning staff of the new procedure, (iii) guaranteeing a constant presence and follow-up of the project.

Figure 6. Team gathered for the pilot project.

A graphic design was developed with: (i) the design and development of easy-to-read information posters for the separation bins, gathering images and texts with the main rules for an efficient separation (Figure 7a), (ii) the development of plans to easily locate the islands aiming to simplify their control and maintenance, (iii) the design and development of awareness posters for the need to reduce the use of paper and water in the bathrooms (Figure 7b), by the students of AmbientalIST, a climate action student group in Instituto Superior Técnico.

3rd phase—Implementation

(**a**) (**b**)

Figure 7. Posters developed in the project: (**a**) information posters for the separation bins, (**b**) awareness posters for the need to reduce the use of paper and water in the bathrooms. **Legend:** Indiferenciado—Undifferentiated; Plástico/Metal—Plastic/Metal; Papel e Cartão—Paper and cardboard; Vidro—Glass; Use menos papel—Use less paper.

This phase began with the distribution of the survey to the building's population regarding Sustainable Habits in the Work Environment. One week later, the new procedure was initiated with the deactivation of the bins in the offices and the placement of 16 separation islands in the common spaces. In parallel, communication posters were posted showing a dashboard for visualizing the results week by week, including the monitoring results from the 1st phase (prior to the new SWM model).

The survey to the building's population allowed us to know the target population of the pilot project. In particular, it was possible to conclude that, on a scale of 1 to 5, on average, respondents indicated that they separate waste (glass, plastic bottles, batteries, and chemical waste from work) regularly (M = 3.99; SD = 1.31). This behavior was positively correlated with age (r =0. 30, p = 0.016), i.e., with age, this behavior gets more frequent. There were no statistical differences between professors or researchers, technical or administrative staff, and students (F (2, 59) = 0.71, p =0. 497). Importantly, participants revealed a strong environmental consciousness (M = 4.37; SD = 0.54) and a positive pro-environmental behavior in the workplace (M = 3.91, SD = 0.57), and there were no significant differences between professors or researchers, technical or administrative staff, and students (F (2, 61) = 2.90, p =0. 063, F (2, 61) = 2.09, p = 0.132, respectively). Users of this building also indicated a strong need to be informed about pro-environmental issues at their workplace (M = 4.04, SD = 0.81) recognizing, however, that the current IST facilities are not sufficient for the separation of residues (M = 1.84, SD = 1.02). Moreover, for these variables, there were no significant differences between professors or researchers, technical or administrative staff, and students (F (2, 61) = 0.90, p = 0.415, F (2, 61) = 1.04, p = 0.361, respectively).

4th phase—Evaluation

The evaluation was possible due to the final monitoring of the new procedure, which revealed excellent results, with 58% of recyclable waste separated after the introduction of the model. The pilot project MFD allowed us to test the model implemented, assess the difficulties, and to identify the key points for a successful implementation across the whole campus. Moreover, carrying out parallel studies integrated in the communication plan (namely the survey on sustainable habits in the workplace) allowed not only to communicate results effectively but also to carry out environmental and economic analyses of the pilot project with results that can be extrapolated to the whole campus.

Figure 8 shows the final results after the implementation of the SWM new procedure.

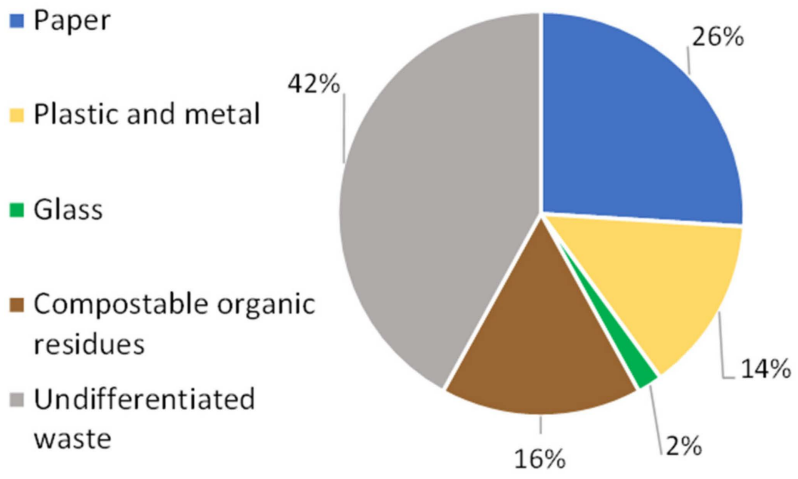

Figure 8. Waste monitoring results after the project implementation.

Considering the amount of waste generated annually in the campus, around 215 tons, the results were extrapolated to estimate the environmental benefits of expanding the SWM new procedure, implementation, and communication to the whole campus. The results were based on the ReCiPe2016 Midpoint (H) LCA method [22] and using the Simapro

software with the Ecoinvent database, as LCA has been the main method used to assess the impact of SW [23,24]. We considered the separation of 50% of the waste, the waste profile in Figure 7, and the scenario of incineration with energy recovery for the organic and undifferentiated waste. Values in Table 1 show the benefits of the separation in several categories of impact, namely climate change (CO_2 eq). It is expected that more than 32 tons of CO_2 eq can be saved annually in one campus. The annual values of waste are average values for the last decade, collected by the campus technical services.

Table 1. Recipe Midpoint (H) results before and after the implementation of the new procedure in the campus, annual values.

	Units	Before SWM New Procedure	After SWM New Procedure	Variation
Climate change	kg CO_2 eq	−21,945	−54,378	−32,434
Terrestrial acidification	kg SO_2 eq	−429	−622	−192
Freshwater eutrophication	kg P eq	0	−13	−13
Marine eutrophication	kg N eq	−2	−138	−135
Human toxicity	kg 1,4-DB eq	132	−13,552	−13,683
Photochemical oxidant formation	kg NMVOC	−111	−325	−213
Particulate matter formation	kg PM10 eq	−123	−280	−157
Terrestrial ecotoxicity	kg 1,4-DB eq	−3	−9	−7
Freshwater ecotoxicity	kg 1,4-DB eq	−14	−594	−581
Marine ecotoxicity	kg 1,4-DB eq	−24	−557	−533
Ionizing radiation	kBq U235 eq	−10,322	−13,098	−2775
Agricultural land occupation	m2a	0	−256,234	−256,234
Urban land occupation	m2a	0	−1642	−1642
Natural land transformation	m2	0	−9	−9
Water depletion	m3	671	−667	−1338
Metal depletion	kg Fe eq	−17,705	−14,702	3003
Fossil depletion	kg oil eq	−22,858	−27,823	−4965

3. Roadmap for Implementing a Sustainable Waste Management Model, Monitoring and Assessment Methods, Communication, and Involvement of the Community

3.1. Roadmap for Implementation

The implementation of the same procedure for waste separation and collection in two universities from two European countries has shown both the need for adaptation to the context, namely regarding budget, regulations, and rules for separation, and the critical points for a successful implementation, common for both. The Italian and Portuguese teams coordinating the implementation in each university maintained contact in the past two years, sharing experiences, methods, successful actions, and difficulties with each project. From both experiences, a simple roadmap was formulated and is illustrated in Figure 9, with the phases, methods, and actions that were deemed crucial for the implementation of the projects in both countries described below.

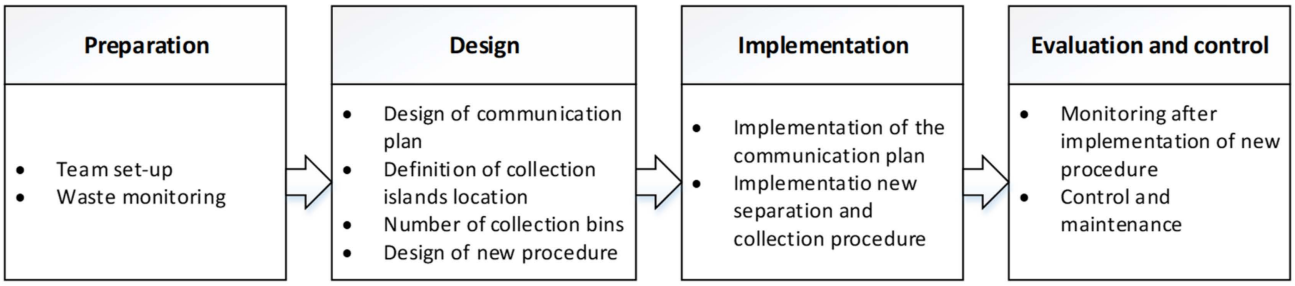

Figure 9. Roadmap for implementing the SWM model.

- Preparation—In this phase, two essential steps are fundamental, a structured team to implement the model and the monitoring of the waste. It is critical to ensure

there is a team capable of carrying out the monitoring before and after the SWM model implementation, the development of an effective communication plan, the design of the new procedure, and the follow-up after the implementation. This means a multi-disciplinary team, comprising management and cleaning staff, students, and the coordinators of the project. The monitoring step is required to assure not only credible results on the evaluation step, but also the adaptation of the waste collection downstream, also optimizing the location and capacity/number of the external containers for collection by the solid waste municipality services.

- Design—This phase comprises the design of the new plan, which should regard not only the practical definition of the new locations for the islands, number of bins, and the collection procedure, but also the communication plan. In the definition phase, the team gathered must define in situ the location of the islands and quantity of bins, taking into account the specificities of each building. It is also required to redimension the exterior containers for the new profile of waste separation. The whole procedure is set with the full knowledge and involvement of the cleaning and office staff, students, teachers, and researchers. This is only possible through effective communication that includes the communication with the cleaning staff, with the management, and with the building users. The experience from Italian and Portuguese universities showed that it is important to create a design plan that imprints an image to the project, a communication procedure to ensure the whole community is aware and involved in the project, and other means such as surveys and interactive apps also proved to increase the project success.
- Implementation—In this phase, the most important aspect is to have the whole team mobilized, as the model should be implemented swiftly, removing the undifferentiated waste bins inside the offices and classrooms and replacing them with the islands in the locations defined in the design phase. In parallel, the team must ensure effective communication with the community, adapting the procedure in spaces with specific needs, namely labs.
- Evaluation and control—The final step is the monitoring of the waste after the implementation phase, the follow-up of the process regarding the feedback of the community and changes where necessary, and the control and maintenance of the new process. The communication plan must also ensure its effectiveness in this phase. The monitoring of the results is useful for the indicators required in most university sustainability rankings today, and impact assessment methods such as the ReCiPe2016 method can be used to assess the reduction in emissions such as CO_2 eq.

3.2. Strenghts and Limitations

This study was conducted in two universities, one of them in a very large scale. Although the SWM was similar, different parallel actions for communication and community involvement were tried. Given also the different resources available in the universities, the materials and type of actions also had to be adapted.

In the Milano-Bicocca case, the SWM was implemented with the support of the university management, and therefore with budget for more resistant materials and for the bottles to offer the university community. Given that the project is more mature, it is scaled to the whole campus and all sustainability initiatives involving the campus are now overseen by a sustainability office, namely the gamification initiative with the PolApp. Although starting as a bottom-up initiative, it was integrated in the university structure.

In Instituto Superior Técnico (ULisboa), the project was purely a bottom-up initiative, with a very limited budget and resources. All participants were volunteers, which gave the project a limitation regarding materials and time, but on the other hand, the whole team formed by staff, teachers, researchers, and students has a sense of belonging to the project from the start. Within this context, it was possible to implement a participative process for designing the SWM and implementing it, with inputs from the users (research offices, building manager, and other staff), the project managers, and the cleaning staff, serving

both as a communication strategy and a way to optimize the procedure. The team that participated in this process is also now capable of supporting the implementation to the other buildings and campuses. Another critical point was the publication of the results and all the communication material and survey, as it increased and extended the sense of belonging to all users of the building.

4. Conclusions

The implementation of an ambitious SWM separation procedure in two European universities is described in this paper, with a roadmap with the main phases and methods that came out from the results and discussions during the meetings of the two universities. The first implementation occurred in 2016 in Milano-Bicocca University, whose SWM model and implementation project inspired the pilot project in Instituto Superior Técnico from Lisbon University. The success of the pilot project led to its extension to the whole school, which is under way. Although in different contexts, the projects have shown that some points are critical, namely a compromised team, a detailed plan, and a good communication plan capable of engaging the whole community. These projects went beyond the basic waste separation, with different actions in the two contexts targeting its reduction and fostering changes in the community behavior regarding sustainability aspects inside and outside the campus. While in Bicocca-Milan the main parallel target was the reduction of plastic bottles, the pilot project in Instituto Superior Técnico aimed at reducing the paper and water use, and the separation of compostable organic waste to use in composters located in the garden, a type of separation that is still not widely implemented in the Lisbon municipality. Although with different targets, all parallel actions served as methods for involving the community, serving as living labs and as drivers for the third mission of any university, the transfer of knowledge outside academic environments to the benefit of society.

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