



The Socio-technical Adoption of Dry Toilets at a Public University in Mexico City (prototype)

La adopción sociotécnica de los baños secos en una universidad
pública de la Ciudad de México (un prototipo)

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Abstract

This paper reports the findings of a two-year project on the relationship between a university community and its sanitation issues, the potential benefits of decentralized urban sanitation, and methods for transforming university culture regarding these topics. Using a public university in Mexico City as a case study, the research included three phases: diagnosis, training, and promotion; design and building a dry toilet prototype; and evaluation. The phases were facilitated through interdisciplinary participatory methodologies. Our approach achieved a significant socio-technical transformation. We also discovered great interest in alternative sanitation systems within Mexico City. This research may help inform interdisciplinary and participatory interventions involving these systems.

Keywords: on-site sanitation; ecotechnologies; participatory methodologies; socio-technical transformation; sustainable urban sanitation.

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Resumen

El artículo aborda los hallazgos de un proyecto de investigación que estudió la relación entre la comunidad universitaria y sus problemas de saneamiento. La investigación se centra en los beneficios potenciales del saneamiento urbano descentralizado y los métodos para transformar la cultura de la universidad en estos temas. Dicho proyecto incluyó tres fases: el diagnóstico, la capacitación y la promoción; el diseño y construcción de un prototipo de inodoro seco; y la evaluación. Las fases se facilitaron mediante metodologías participativas interdisciplinarias.

Palabras clave: saneamiento en sitio; ecotecnologías; metodologías participativas; transformaciones sociotecnológicas; saneamiento urbano sustentable.

Introduction

The past 20 years have seen exponential growth in the number and size of cities worldwide, giving rise to a series of complex issues (Castaños-Lomnitz, 2005). On the one hand, cities are hubs of economic, social, and cultural activities. On the other, modern urban practices create unsustainable situations resulting from waste generation, environmental pollution, resource depletion, mobility issues, poverty, and overcrowding. In these situations, systemically tackling urban challenges, such as simultaneously addressing environmental (climate change, pollution, resource overexploitation) and social (extreme poverty, poor health, peri-urban encroachment) issues becomes necessary and requires groundbreaking solutions.

Cities must therefore establish mechanisms to allow the continuous creation of holistic innovations. According to the World Economic Forum (2015), these new urban solutions must incorporate four key principles. First, they must unleash spare capacity, in other words they must utilize resources intelligently (reuse, recycle, upcycle). Second, they must reduce consumption peaks (in water, electricity, and road and public transport use), which can reduce and manage demand while offsetting the burdens on financial and natural resources. Third, they must include small-scale infrastructure thinking, such as cycle and pedestrian paths and decentralized systems, which have a large, positive impact on quality of life in the city. Finally, solutions should be people-centered, able to address the diversity of urban citizens. To adhere to these principles, solutions require multi-faceted frameworks that will support their development (Olcina-Cantos, 2011).

Following this logic, in this paper, we focused on developing an integrative (socio-political and technological) approach to sustainably address urban sanitation issues. This article reports the findings of the two-



year research project “Socio-technical Transformation for the Sustainable Management of the University’s Organic Waste” (2015-2017) funded by the Rectorate’s Interdisciplinary Research Program (RIRP) at the University (U). The aim of the project was to drive the transformation of the habits and culture of the U community towards the adoption and action of sustainable values and technologies in human waste management.

Using U as a laboratory, the formulation and implementation of a sustainable sanitation system was explored as a socio-technical transition phenomenon (Smith et al., 2010; Ramos-Mejía et al., 2018) facilitated through interdisciplinary participatory approaches. We held workshops to identify the waste management and sanitation problems at U. We also assessed the willingness to adopt decentralized sanitation practices using surveys and the possible benefits of on-site sanitation. In addition, we studied the design and implementation of a urine diversion dry toilet (UDDT) prototype within the framework of waste valorization, problem-driven (Kruger and Cross, 2006) and permaculture design, using participatory co-designing and co-building methods. The core innovation of this work lies in merging two different disciplines: social studies to examine the adoption of sustainable sanitation values and second-order disruptive technologies⁴ (Schuelke-Leech, 2018) in a specific urban social group (U); and biological engineering to guide the design and operation of the UDDT prototype as an urban ecological engineering technology (ecotechnology).

This paper presents our study in five parts. First, we introduce an interdisciplinary theoretical framework that enables the study of urban on-site sanitation practices. Second, we describe the U community and the work of the institution and its values regarding sustainability and organic waste management as precursors to the study. Third, we include the methods used to conduct the research. Fourth, we present the research findings and results. Finally, we provide concluding remarks and recommend follow-up actions.

Theoretical Framework

Twenty-first century cities will need to become highly sustainable and resilient to overcome modern challenges that include regional climate change and commercial globalization; local accelerated urbanization, demographic changes, and economic restructuring; rising trends in participatory governance and the need for sustainable municipal services (Strange, 2018). Cities will need to make net positive contributions not just to anthropocentric systems, but also to their socio-ecological systems (SESs) (Zaman and Lehmann, 2013; Forlano, 2016; Yigitcanlar et al., 2019).

⁴ “A second order disruption [is a change with] larger influences, affecting many industries and substantially changing societal norms and institutions” (Schuelke-Leech, 2018).



One area in need of change to meet these emerging challenges is the conventional (centralized) sewage utility, which tends to lack the flexibility required to deal with the challenges listed above (Bieker et al., 2010; Gilrein et al., 2019). However, designing, implementing, operating, and maintaining innovative sanitation solutions is difficult and complex. For instance, distributed sanitation configurations act as second-order disruptions and include technological, managerial, and social implications, all of which act as significant barriers to their implementation and operation within the tightly regulated, infrastructure-heavy sanitation industry. Moreover, the current perception is that the procurement and management of sanitation services are the responsibility of the state. In other words, sanitation problems are seen as signs of government negligence and failure, while citizens are thought to have no individual responsibility over them. Further, conventional utilities are often markers of urban citizenship through infrastructure and participation in “desirable” hygiene practices (Bakker, 2010; Chatterjee, 2004; Gandy, 2011; McFarlane and Rutherford, 2008).

UDDTs have been studied as modern on-site alternatives to centralized sanitation systems since the 1950s, when they were launched in Vietnam. By the 1970s, they had been adapted to new urban needs in the USA and Guatemala. César Añorve became a pioneer of this technology in Mexico in the 1980s (Rizzardini Villa, 2010). Añorve established the Center for Alternative Technological Innovation (State of Morelos) to address the local degradation of ravines due to direct sewage discharge through the promotion of an environmentally minded water culture. The Center developed ecotechnologies such as rainwater harvesting and the so-called “Ecological Dry Toilet” for both households and ecovillages⁵ (Centro de Innovación y Tecnología Alternativa, 2003). In 2006, in Inner Mongolia in China, the EcoSanRes Program funded the construction of a town with five buildings, a kindergarten, a small shopping center and 825 apartments with decentralized sanitation (www.ecosanres.org). Since then, multiple worldwide pilots of these ecovillages have arisen from public-private investments (Morgan and Shangwa, 2010; Winblad and Simpson, 2004).

On-site sanitation solutions must be further developed to address the multiple challenges to increasing their adoption in cities (Mallory et al., 2020). Conventional sanitation systems are rigid, uniform, gray infrastructure configurations, constraining and incapacitating the urban ecosystem, while new, effective urban sanitation approaches can lead to a “fluid mosaic” configuration, which includes distributed approaches that are diverse, adaptable, and responsive to local SES conditions (Cordova and Knuth, 2005a). In this type of configuration, centralized systems are functional and well managed while capable of introducing and combining new practices with modern eco-techniques that make it possible to integrate

⁵ Ecovillages are intentional, alternative, and cooperative communities that include sustainable practices (Daly, 2017).



on-site sanitation systems according to the characteristics of the territory. This includes climate, geographic, environmental, and socio-cultural conditions. This means that socio-technological prototyping of novel urban sanitation systems will be required. A fluid mosaic means knowing how to combine best practices. UDDTs are not only suitable for agricultural communities; nowadays, various prototypes have been launched in different cities such as China, Vietnam, Norway, Sweden, or India.

In this paper, we study a UDDT as a sustainable sanitation approach by incorporating environmental, economic, technological, and socio-cultural aspects into its implementation.

Environmental Dimension

Cities must develop and implement concerted and strategic plans to achieve ecologically appropriate sanitation services. Conventional flush toilets and their associated sewerage management systems are infrastructure and resource intensive, can cause high volumes of polluting byproducts (such as greenhouse gases and waste activated sludge), and may emit hazardous waste during operational upsets (Cordova and Knuth, 2005a; Chanakya et al., 2009; Holm-Nielsen et al., 2009). For cities to improve their ecological efficiencies, these environmental impacts must be avoided in current and future solutions.

Dry toilets, including UDDTs, are considered environmentally appropriate alternatives to water-based sanitation management systems, which comprise excreta disposal, isolation, storage, and treatment (Morales et al., 2014). UDDT designs are based on the concepts of environmental protection and disease prevention, and tend to use a range of biotechnologies (such as composting or urine fermentation) to stabilize and treat human waste. Dry toilets provide ecologically prudent sanitation, based on the principles of recycling and upgrading waste by recovering nutrients from stool and urine. These toilets provide a broad range of direct environmental benefits, from water savings, a fundamental issue in cities, to eliminating soil contamination, since the contained treatment prevents contact between biohazardous waste and the ground or discharged water (Más por Ellos, 2016). Despite their environmental suitability, however, dry toilets tend to lack economic, technological, and social dimensions in their design. To increase their uptake in cities, dry toilets must therefore be re-designed as complete sanitation solutions.

Economic Aspects

Within the economic sphere, both conventional and novel sanitation solutions must overcome significant hurdles. Conventional systems give



priority to the immediate separation between individuals and their human waste, forgoing effective resource recovery strategies and requiring high financial and infrastructure inputs (Esrey et al., 2001; Morales et al., 2014; Paterson et al., 2007). For instance, it has been estimated that the capital costs of sewage systems can be up to ten times higher than that of on-site fecal sludge (FS) management systems (\$42.66 USD capita⁻¹ year⁻¹ vs. \$4.05 USD capita⁻¹ year⁻¹) (Dodane et al., 2012). In addition, novel (distributed) systems tend to require significantly fewer resources to operate, such as water, energy and building materials. Since collection and treatment are done on-site, it is possible to locally valorize excreta as commercial products, allowing for economic and resource savings, which in turn can become self-financing strategies (Costner, 1990; Otterpohl and Buzie, 2013; Esrey et al., 2001; Del Porto and Steinfeld, 1999; Semiyaga et al., 2015). Considering that most urban design and municipal asset management is based on conventional wastewater systems, distributed solutions must create profitable economic schemes if they are to be implemented on a larger scale (Morales et al., 2014; Paterson et al., 2007; Dodane et al., 2012; Jewitt, 2011; Ludwig and Kumar, 2000).

The lack of research and development investment in alternative sanitation approaches has also contributed to their high failure rates, with 30 % to 70 % of all projects worldwide breaking down within a few years of implementation (McConville and Mihelcic, 2007; World Bank, 2003). Most critically, failures are also due to insufficient participation and acceptance by communities. City dwellers tend to have a strong attachment to centralized systems and equate them with economic development since they are large infrastructure investments. This means that non-centralized systems are perceived as inappropriate for cities (Katukiza et al., 2010; Sohail et al., 2005; Jewitt, 2011; Morales et al., 2014). New sanitation solutions should therefore actively engage users to address their context-specific needs (Bocken et al., 2014).

Technological Issues

In general, dry toilets, such as UDDTs, are on-site technologies applicable to any type of building (domestic and industrial; private or public) (Del Porto and Steinfeld, 1999). UDDTs were originally designed around the safe reuse of excreta, their main components being source-separation (separation of fecal matter and urine from the origin), waterless fecal management and treatment, and ventilated chambers or containers for feces storage and treatment. However, the design criteria have gradually expanded towards broader objectives, such as enhanced comfort (for example, quick odor elimination, fewer manual operations, and reduced contact with excreta) and treatment versatility to address diverse geographical and economic contexts.



Various peri-urban applications of UDDTs have been conducted. In Lima, Peru, and Thekwini, South Africa these efforts included low-tech approaches and were mainly designed for marginalized communities (Morales et al., 2014; Katukiza et al., 2010; Strande, 2014). Cordova and Knuth (2005b) analyzed the user satisfaction of UDDTs in five Mexican cities in communities with various socio-economic levels. They found that most users were content with these devices due in part to the ongoing monitoring and encouragement of experts and the associated support and maintenance services provided. Regardless of users' socio-economic status, these systems were found to be accepted by users inside their homes if they were aesthetic, included an external service for waste collection and maintenance, and reduced water consumption levels and associated costs. The analysis of UDDT installations in various urban contexts is an important step to understanding how they can best be adopted more widely.

Beyond having an effective front-end interface, UDDTs also require suitable back-end operational guidelines. Few engineering practices have been designed for the monitoring, operation, and maintenance of these solutions (Semiya et al., 2015; Anand and Apul, 2014). In Mexico, the *École para la Vida* organization created a manual for the construction of ecological dry toilets. This manual uses cartoons and non-technical language to provide information on how, when, and where to build this type of project. It specifies suitable conditions, building materials and land layout, and includes usage and maintenance instructions. In addition, the manual highlights the benefits of the closed-loop cycle of urine and excreta (Añorve, 2008). However, the extensive application of these methods poses a challenge in peri-urban and urban communities since they are extremely heterogeneous spaces with diverse scales and densities. New technologies must therefore address diverse urban SES contexts, as well as the activities to guarantee their effective, systemic operation (Larsen et al., 2016).

Socio-cultural Considerations

Technologies tend to be incorporated into local contexts via broad multi-stakeholder (social, economic, political) processes of imagination. These complex processes include both material and semiotic dimensions, where individuals imagine themselves and their relations to others through the technologies adopted. Consequently, technological appropriations imply socio-cultural appropriations, produced both collaboratively and collectively (Lindtner et al., 2012). In the case of UDDTs, it has been observed that they have low acceptance, and they are considered impractical due to the physical proximity to and required interaction with excreta. This perception stems in part from the “comfortable lifestyle” associated with urban living, which includes getting away from “waste” (Morales et al., 2014). Another important aspect is that both users and municipalities lack the knowledge and capacity to provide maintenance for UDDTs or troubleshoot possible failures and



disruptions, since there are no socioeconomic or technological ecosystems to support these distributed sanitation systems (Añorve, 2008).

In general, urban communities and their public servants avoid distributed sanitation systems. Most city inhabitants and employees do not know what they are, what their advantages and disadvantages are in urban settings, or how and when it is feasible to implement them. Moreover, there are no clear relations between stakeholders that can benefit from on-site technologies, so UDDTs are not currently part of urban ideals.

The socialization and adoption of decentralized sanitation practices can be facilitated through side-by-side governance practices (Alfie and Cruz-Bello, 2019a; Pahl-Wostl et al., 2008). Governance can function as a structure and a process of coordination and directionality, which, in turn, can promote arrangements and agreements between different socio-political actors. Overall, governance includes a dynamic grassroots space with intertwined networks of practical ideas and cooperative mechanisms among a group of actors with concrete interests (Santos and Gomes, 2007). In this respect, knowledge-sharing, participatory decision-making, and collaborative dynamics, such as co-designing and co-building activities, can play a fundamental role in facilitating the acceptance of technologies such as UDDTs (Morales et al., 2014; Cordova and Knuth, 2005b).

Socio-cultural changes imply a reformulation of the perceptions and actions of various actors. It is important to analyze the relationship between centralized and decentralized systems where the scheme implies being able to select the best practices in a territory in a “fluid mosaic” way. This relationship encompasses the services that the government must provide and citizen participation in joint solutions related to environmental problems. Last, but not least, education and information are a means of transforming practices and prejudices against new technologies.

In summary, UDDTs, although environmentally suitable solutions, must be redesigned to include the economic, technological, and social-cultural dimensions of urban contexts. Based on what has been presented above, the redesign process must be an interdisciplinary effort that includes identifying and defining the problem and corresponding solutions through a collaborative framework between experts and the target community. The first step in social change includes informing stakeholders of the challenges and corresponding opportunities of different sanitation solutions. Stakeholder engagement is necessary in the problem definition processes and in co-creating solutions. In addition, a collaborative framework must be built and agreed upon by the stakeholders, which considers the sociocultural aspect of sanitation.

We can therefore state that although dry toilets have multiple advantages, their implementation poses significant challenges (Table 1).



Table 1. Future, Challenges and Probable Solutions of Urine-Diverting Dry Toilet (UDDT)

UDDT Challenges	Issue	Probable Solutions
Environmental	UDDTs are complex, on-site sanitation solutions encompassing diverse unit operations: excreta disposal, isolation, storage, and treatment. This can increase the potential for local pollution events in each of these units if they are not properly operated	Re-design as complete sanitation solutions adapted to the ecosystem they are operating in (for example desert vs. rainforest)
Economic	Lack of research and development investment in alternative sanitation approaches from governments and private investors. Lack of awareness of economic benefits.	Promote public and private investment Develop environmental markets Study circular-economy models Promote economic-ecological benefits Foster eco-entrepreneurship initiatives
Technological	Shortage of suitable back-end operational guidelines Few engineering practices generated around the monitoring, operation, and maintenance of these solutions	Research and develop engineering best practices concerning monitoring, operation, and maintenance Produce innovative techniques and designs
Socio-cultural	Low acceptance Prejudice Mistrust Lack of knowledge Lack of environmental culture Absence of economic, technological, and social dimensions in their design	Produce outreach material on environmental and sustainable sanitation education, information, and governance Leverage cultural customs Improve environmental practices and make related information and education widely available. Encourage environmentally sustainable norms and legislations. New environmental instruments (markets, political participation)

Case Study

U was used as our case study because of its identity as a sustainable campus. Since its founding in 2005, U has continually strived to maintain a cutting-edge higher education model and has subsequently made sustainability one of its core principles and fundamental fields of work. Consequently, at U, sustainability is an essential focal point and approach that engages in interaction with the local context and the university environment; permeates the institution's field of education (study programs and plans) and research; and guides the campus' property management and cultural practices.



At U, the concept of sustainability involves the ongoing maintenance of suitable environmental conditions, the ability to reduce social injustice and inequality, and redistribute wealth. U analyzes environmental issues from both technical and social perspectives. Thus, this sustainability framework allows for the elimination of conditions that reduce the quality of life through scientific and technological development, and it may also be a benchmark for assessing factors that cause poverty, unemployment, hunger, and exploitation.

In 2016, U's Environmental Management Project (EMP) initiative emerged to promote a responsible environmental management based on the development of processes in line with current regulations that would guarantee the control and reduction of environmental impacts, through teaching activities, research and preservation and dissemination of culture.

EMP strategies included the socialization of action programs; preventing environmental impacts generated by university operations; preserving areas for environmental opportunity; reducing greenhouse gas emissions; promoting rational, efficient consumption of energy and natural resources, emphasizing waste separation, recycling, the reduction and reuse of materials, management of treatment waste; as well as promoting green procurement; sustainable management of green areas and sports spaces.

During the time of the study (2015 to 2017), U had nearly 2000 students, 293 administrative staff, and 208 research fellows in a three-hectare campus, which included one hectare of green space. For this research, a crucial precursor was U's Integral Management of the University Solid Waste Program, whose key principles were waste reduction, waste source separation and recycling. In the first year of operation, the program recycled nearly two tons of solid waste. In addition, 54 tons of food waste from the university's cafeteria were sent to a local livestock farm (Alfie and Garcia-Becerra, 2018). Since the university's community was already aware of the importance of waste separation and valorization, it was a small step to broaden the context of sustainable management and upgrading of organic waste to sanitary waste.

Methods

In this study, we sought to understand the relationship between an urban university and its sanitation system, identify the benefits to the university that sustainable sanitation could provide and support the transformation of the university's sanitation culture and habits. All activities included a participatory, side-by-side, face-to-face methodology (Alfie and Cruz-Bello, 2019b) for the identification of urban sanitation issues, as well as the design, implementation, operation, and sustained use of a UDDT prototype. This two-year project was divided into three phases: 1) diagnosis, training, and



promotion (first year); 2) design and prototype (second year); and 3) evaluation. The methods used for each phase are described below.

Phase 1. Diagnosis, training, and promotion (first year)

It has been shown that participatory methodologies can contribute to reaching agreements between a population and its authorities to solve complex issues, such as environmental ones. The involvement of stakeholders not only permits their participation, but also makes it possible to collectively deliberate and act on the problem at hand. To address the challenges related to issues such as urban sanitation, participatory methodologies can be processes where a mosaic of actors influence how a technology is accepted, managed, and implemented (González et al., 2008). Horizontal communication among the various actors is key to raising awareness, identifying alternatives and, ultimately, supporting decision-making. These methods are instrumental in seeking actions to mitigate risks and facilitate the readiness and openness to change of communities (Canevari-Luzardo et al., 2017; Cruz-Bello et al., 2018).

The diagnosis phase included first forming a working group, the Diagnosis Working Group (WG1), which conducted participatory-based diagnosis, to understand the community's perceptions of sanitation in general and UDDTs in particular. The WG1 consisted of 20 members of the university community, mostly students from various bachelor programs and professors and campus workers, including unionized administrative and maintenance staff. The WG1 was formed through a university-wide call through email informing the U community of the project and the opportunity to participate. The diverse makeup of the group was intended to improve the scope of the impact on all sectors of the university by facilitating a horizontal discussion between peers. The WG1 was then continuously trained throughout the 2015–2016 school year in on-site waste management ecotechnologies (such as composting), participatory methodologies, and the promotional skills required to reach out to the rest of the university.

Once trained, the WG1 developed and presented a participatory diagnosis workshop, including a survey at the end of the session on sustainable sanitation to 1) obtain feedback from the U community on its water sanitation issues; 2) inform participants of on-site solutions; and 3) gauge the perception of having a UDDT in campus. The workshop's objectives were to encourage the transformation of conventional ways of thinking and acting in relation to water and sanitation and to highlight the importance of natural, holistic, and closed cycle systems for water, nutrients, and organic waste. A deliberative approach was fostered so that participants could determine and evaluate four main topics, by first inquiring about participants' knowledge on the topics and then presenting them with information relevant to these topics (Alfie and Cruz-Bello, 2019b). The four topics included 1) the participants' sanitation situations in their homes and at the university; 2) decentralized systems for



water and sanitation service provision; 3) U's programs related to organic waste management and the potential valorization of sanitary waste; and 4) participants' perception and possible approval of the implementation and use of UDDTs in the university facilities.

The two-hour workshop was given during U's "Annual Sustainability Day", a one-day annual event where the university's sustainability-related activities and research are showcased. The workshop was simultaneously given to a total of 400 students from different undergraduate programs. These students were distributed among 12 groups of 30 to 35 people. Three participatory activities were included during the workshop, which were calibrated for the U community and context (classroom size, audiovisual equipment availability). The experience of running these activities helped us plan the co-designing activities for the following phase. At the end of the three activities, a written survey of 10 questions was anonymously answered by the participants.

Phase 2. Design and prototype (second year)

Once the main sanitation issues and related perceptions of the U community had been identified in the workshop, the second phase was started, which included collectively identifying and establishing multidisciplinary (social, cultural, and technological) design objectives. The design process was conducted with another working group, the Co-design, and Co-building Working Group (WG2), with 35 students. This group included both members of the WG1 and new members, due in part to the turnover rate in the U's student body. The new members were mainly drawn from undergraduate elective courses designed specifically for this project phase, which were offered in the schools of Natural Sciences and Engineering (NSE), and Social Sciences and Humanities (SSH), and included four bachelor's degree programs: Design Studies, Biological Engineering, Molecular Biology, and Socio-territorial Studies.

The UDDT's engineering design, the standardized operating procedures (SOPs) for its operation, maintenance and monitoring, and the processing scale-up plans were produced in the NSE elective courses. At the same time, the participatory methods and survey designs were established in the SSH elective courses. In addition, there were activities for all these courses outside the classroom, which included visits to the building site and a three-day trip to a self-sustaining ecovillage (Instituto Tonantzin Tlalli, State of Oaxaca, Mexico) where the WG2 members lived as first-hand users and operators of decentralized ecotechnologies, including UDDTs.

The architectural layout of the UDDT was co-designed with the WG2 and Lilly Wolfensberger-Scherz, a permaculture and ecological architecture specialist. This phase also included collaboratively building the UDDT out of cob and ferrocement with the WG2 and the university's community at large to foster its connection to the prototype over a five-week period. The eight-



hour co-building sessions were held daily as drop-in workshops with four ecological building experts instructing and supervising participants.

The co-design and co-building phase incorporated design thinking (Fabri, 2015; Withell and Haigh, 2013; Gould et al., 2019)⁶, ecological engineering (Ewing and Fridley, 2017)⁷, and permacultural principles and design methods (Wolfensberger-Scherz, 2005)⁸ ⁹. These socio-technical collaborative frameworks were selected since they foster holistic and intuitive multi-dimensional problem-solving techniques to match people's needs with what is technologically feasible and organizationally viable. We followed the five-stage process of design thinking (empathizing, defining, ideating, prototyping, and testing) and adapted it to the characteristics of the U. During the defining stage, the persona¹⁰ (i.e. the user-operator¹¹ in the Persona Method) was a construct of the participants' personal and professional backgrounds, and their multidimensional design objectives and interests (Chasanidou et al., 2015).

Moreover, action-research group-management principles¹² were used to facilitate the creation of a unified, interdisciplinary language and conceptual framework, as well as a baseline of socio-technical knowledge (Montoya, 2008). This common ground was built so participants from diverse social and disciplinary backgrounds could horizontally partake in the creation and proposal of solutions and their implementations. In addition, the action-research approach helped reveal the evolution of the re-iterative design process: diagnosis-planning-action/observation-reflection-transformation/replanning cycles, which can visibilize the transformation of social practices through the creation of new knowledge (Colmenares et al., 2008).

⁶ Co-design is a design-led process that uses creative participatory methods. There is no one-size-fits-all approach or a set of check- lists to follow. Instead, there are a series of patterns and principles that can be applied in different ways with different people. Co-designers make decisions, not just suggestions.

⁷ Ecological engineering has been defined as the design of ecosystems for the mutual benefit of humans and nature.

⁸ Based on the precise observation of how ecosystems work (particularly in terms of productivity and efficiency), permaculture draws on non-fixed modes of design that are adaptable to the fields of application. The result is a method of universal principles known as "permacultural design". Permacultural design (the word "design" here includes the notions of project and process of realization) is based on three founding ethical requirements: preservation of the environment and biodiversity; willingness to build a community for individual and collective well-being and sharing of resources and equitable redistribution of excesses (for the benefit of humans and the environment).

⁹ Design thinking is a process for solving problems by prioritizing the consumer's needs above all else. It relies on observing, with empathy, how people interact with their environments, and employs an iterative, hands-on approach to creating innovative solutions.

¹⁰ The persona is a synthetic construct of an average user (in this case the user is also an operator) of the UDDT considering its previous knowledge, competencies and needs.

¹¹ A user-operator is a user who is also responsible for the performance of the technology they are using. For example, a user of a smartphone is also in charge of maintain the device's software updated for its adequate performance.

¹² This refers to guidelines to manage a heterogenous group of individuals in action-research projects, which are highly creative and where productive exchange of ideas is necessary and requires facilitation.



Phase 3. Evaluation

Four months after the completion of the second phase, the degree of sociotechnical transformation in the project's WG2 members was measured through an anonymous survey. The survey had three objectives: a) to measure the level of knowledge the WG2 members obtained regarding the project's main issues (waste source separation, waste biomass valorization, and selected technologies (composting and UDDTs); b) to assess the change in values regarding waste biomass and its perception as a resource; and c) to evaluate the change in actions due to the potential change in values. These three factors were used as indicators of socio-technological appropriation of the implemented UDDT.

It is important to note that the UDDT project was well received and supported by the institution while it was conducted. Throughout the two years of this study, the lead researchers were in constant contact with U's administration. Open communication was maintained regarding the evolution and impact of the project. In addition, two annual reports were submitted to, evaluated by, and approved by the RIRP. Further, these reports were disclosed for public access on the institution's official website. The administration of that time promoted and funded various sustainability projects in teaching, research, and campus management, which included this study.

UDDT is a prototype laboratory that will make it possible to implement major changes in the environmental culture of the University and, in the long term, to replace common bathrooms with this type of ecotechnology. Plans are in place to change male urine toilets during the first stage.

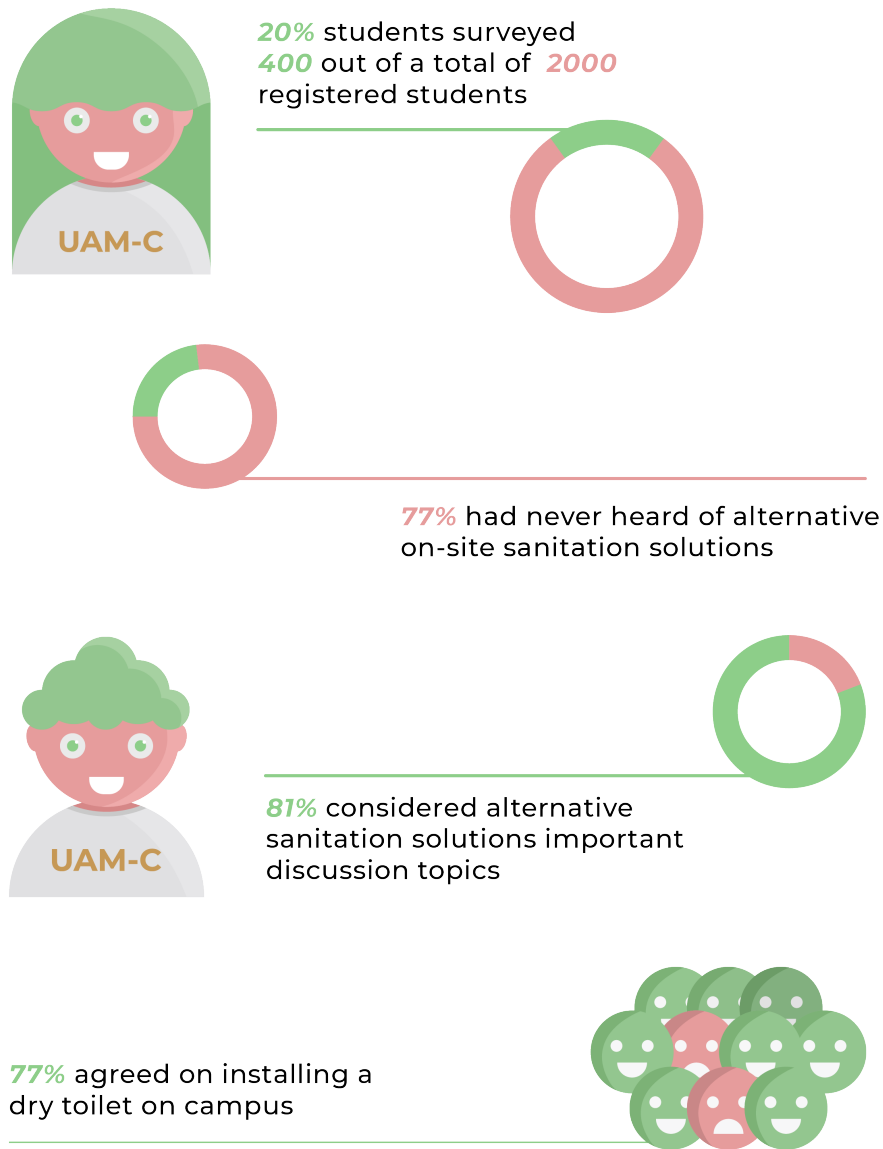
Results

Phase 1. Diagnosis, training, and promotion

In the first year, the WG1 delivered the workshop to a total of 400 students (~ 20 % of the total student body) from different undergraduate programs in 12 sessions of 30-35 students in each. The workshop included audiovisual material and participatory diagnosis activities and a survey at the end of the session. From the surveys, most students (77 %), who were all urban dwellers, were unaware of different sanitation systems prior to the workshop. However, once the students learned of these solutions, 81 % of the students considered it important to know about them. Moreover, 77 % of students agreed with having a UDDT implemented at U, citing sustainable water management and resource reuse as key reasons for adopting them. A total of 23 % did not agree with having a UDDT at U because they did not know enough about this technology or did not consider UDDTs useful. The survey highlights are presented in Figure 1.



Figure 1: Survey highlights during the first phase of the study



These results indicated the need to raise awareness of urban sanitation issues and to improve the dissemination of information on sustainable sanitation across the campus. To address this need, several outreach activities were carried out to promote the project during the second year. These activities included a social media campaign; designing and teaching



three elective undergraduate courses on ecotechnologies (two at the NSE school and one at the SSH school); organizing a seminar series on urban ecotechnologies (dry toilets, urban agriculture, and wetlands); designing and broadcasting audiovisual material specially produced for this project; and setting up a website for this project (Programa Manejo Sustentable de Residuos Orgánicos, 2017). These tools were designed to keep in touch with the university's community and increase its participation in the project.

These promotional activities were successful. During the second year, 20 students enrolled in the elective courses, 150 participants attended our seminar series and the Facebook group set up to inform and update the community on the construction and status of the project attracted 180 followers.

Phase 2. Design and prototype

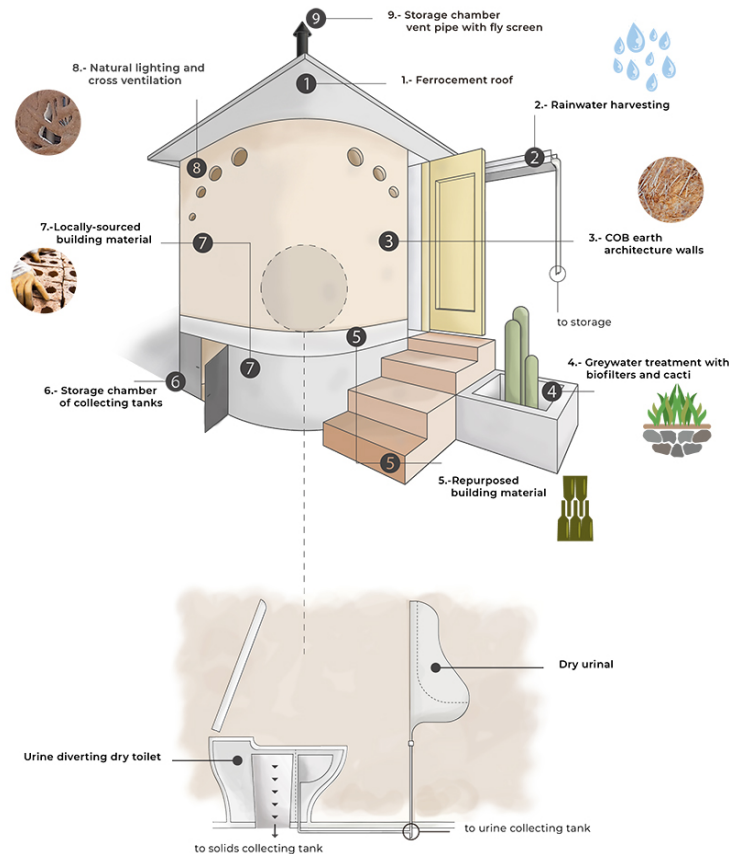
Three design thinking collaborative sessions were held with the WG2. The co-developed design objectives established for the UDDT were divided into three aspects:

- Social: Reach out to the community, contribute to U's social responsibility efforts, strengthen U's mission regarding sustainable development, create awareness of sustainable sanitation, transform sanitation practices, build the community
- Cultural/status: Gain a reputation as a pioneering university in sustainable sanitation, foster innovative interdisciplinary practices, achieve leadership in sustainable sanitation, debunk myths regarding sanitation
- Technological: Implement ecological engineering and permacultural design principles, include resource recovery (nutrients and energy) and innovative technologies, carry out closed-loop resource management.

These design criteria were identified and agreed on by the permaculture expert, researchers involved in the study (specialists in environmental sociology and biological-ecological engineering), as well as the WG2. The criteria were then incorporated into the architectural design of the UDDT. As a result of this process, the UDDT design requirements included the following sustainable features (Figure 2):



Figure 2: Diagram of urine diversion dry toilet at the Autonomous Metropolitan University, Cuajimalpa Campus (The Dry Toilet Laboratory (Spanish acronym LABS))



- Ferrocement roof (building technique that reduces cement requirements)
- Rainwater harvesting (closed-loop water use)
- COB (earth architecture) walls
- Greywater treatment biofilter (using cacti, salinity-tolerant plants, to treat greywater)
- Repurposed building material (from U's construction and recovered glass bottles provided by students)
- Naturally ventilated storage chamber (for waste collecting tanks)
- Locally sourced building material (clay, sand, stones, grass, hay, and cacti-based paint)
- Natural lighting and cross ventilation



These features were selected based on their ability to improve the use and reuse of local resources in the UDDT (such as natural light, ventilation, water and building materials).

It is important to note that as part of our action-research approach, both the design criteria and UDDT's features were first proposed before the WG2 visited the ecovillage. After the WG2 had experienced the UDDTs and other on-site systems in the ecovillage during their stay, the design criteria and features were revisited. We observed that prior to the trip, when WG2 members were learning theoretically about on-site practices, most were enthusiastic about ecotechnologies, including UDDTs. However, as users of the UDDTs in the ecovillage, there was some confusion about how to properly use them and opposition to adopt the new technology. We also observed that female students showed the most resistance to UDDTs (“... I see a black hole I do not like ...”), particularly during menstruation. This was discussed and reflected on with the WG2 to highlight the importance of reiterations during the design process.

The feedback on resistance to usage when the WG2 was interacting with the UDDTs meant that the specific prejudices linked to the experience of UDDTs were key parameters to be addressed in our design. Instructions were designed and posted as fixed signs on the walls on how to use the UDDTs. In addition, an infographic was generated where questions related to urine, excreta and menstruation were answered.¹³ Inside the UDDT, a hand sanitizer dispenser (gelled alcohol) and mosquito nets were installed. This was done to address the needs, interests, and concerns of the community.

The proposed UDDT on-site treatment technologies included the production of electricity from urine by microbial fuel cells and accelerated humanure composting using the Bokashi technique (Footer, 2013). These technologies were selected based on their ability to upgrade human waste as quickly as possible while creating high-value products for city-dwellers, such as electricity and soil conditioner. Further, SOPs and worksheets were developed in the elective courses by Biological Engineering students to have clear instructions on how to use, operate and maintain the UDDT, for both users and operators.

The UDDT was then built collaboratively over for weeks by 55 volunteers, which included the WG2 together with additional volunteers from outside UAM-C. Since the co-building sessions were widely advertised, we had the participation of multiple people from UAM-C's surrounding towns and neighborhoods, including students from a neighboring private university (Universidad Iberoamericana) and U's across-the-street neighbors (16 de Septiembre Street). Volunteers also came from faraway

¹³ Link to the infographic: <http://www.cua.uam.mx/proyectos-sustentables/programa-manejo-sustentable-de-residuos-organicos/proyecto-bano-seco-uam-c>



points of Mexico City (Iztapalapa and Xochimilco boroughs) and the State of Mexico (Tlalnepantla and Teotihuacán de Arista Municipalities). The finished UDDT building is now a dry toilet laboratory (Laboratorio de Baños Secos, LABS, for its Spanish acronym).

The co-building activity gave significant exposure to our work. For example, U's independent student magazine produced an information capsule on the construction process (La UAM Cuajis, 2017). In addition, the LABS inauguration was attended by 87 people from both inside and outside the U (UAM Cuajimalpa Oficial, 2017). Furthermore, we have been interviewed by several national media outlets. This external coverage clearly indicates that people in Mexico City are interested in learning about alternative urban sanitation solutions. This level of engagement with the project both within and outside the university was unexpected, considering the low adoption and interest levels in cities observed elsewhere (Morales et al., 2014; Larsen et al., 2016).

Phase 3. Evaluation

After the school term during which the co-building sessions took place, we surveyed WG2 members on their interest and knowledge of UDDTs. We found that

- 78 % have accurate (from a basic to an expert level) knowledge on composting and UDDTs
- 80 % value source-waste separation and waste biomass valorization
- 83 % have changed their habits regarding waste biomass (source separation, reuse or compost organic waste, waste reduction)
- 70 % have influenced their close social circle (family, housemates) regarding waste biomass (source separation, composting, waste reduction)
- 80 % considered the participatory methodologies (including DT activities) effective in enhancing ownership of the project
- 90 % agreed that the LABS has a medium to high profile within the university

These results indicate that this project was able to change participants' attitudes towards on-site sanitation treatment and promoted a change in actions towards more sustainable behavior regarding organic waste.



Discussion and Conclusions

In this study, we created an interdisciplinary intervention by introducing a decentralized sanitation socio-technological solution in a public university space (U) in Mexico City. Our project used an interdisciplinary approach to develop a UDDT prototype based on the World Economic Forum's four design perspectives:

- use resources in an intelligent way by creating the capacity to reuse, recycle and transform excreta (unleash spare capacity)
- reduce the impact of sanitation on the natural environment (reduce consumption peaks)
- implement an effluent-less on-site UDDT (small-scale infrastructure thinking)
- include U and other communities for the duration of the project (people-centered creations)

Environmentally, we not only addressed the single problem regarding the need for sanitation, but also included a comprehensive vision of the environmental problems of the campus and implemented water collection and savings (through the selected technologies), reuse of resources and the recycling of materials during the construction phase. Above all, we used a participatory, side-by-side, face-to-face methodology to involve the community, and record and integrate their environmental concerns, such as water scarcity, water reuse and sustainable water and waste management. Furthermore, we focused on strengthening their participation and deliberation, based on concrete actions, such as actively designing and building the UDDT.

From an economic viewpoint, our aim was to create a system that could provide a circular economy approach to cities that considers the perceptions, needs and available resources of urban users for the design, construction, operation, and maintenance of these solutions. We selected technologies that created valuable resources from human waste in cities, such as electricity. It is important to note that these technologies are still novel and being developed. The full picture of savings, scalability and potential for circular economy will be tested over time and as their technological readiness level advances. We also focused on reducing capital costs by using locally sourced materials and incorporated the recycling of some construction materials. Moreover, we applied new technologies using urban SES contexts and standardized the activities involved in the monitoring, operation, and maintenance of a UDDT.

In terms of technology, we used design thinking, ecological engineering and permacultural principles and design methods. This enabled us to create socio-technical collaborative frameworks, with an integrative, intuitive,



multi-dimensional, systems-thinking, problem-solving approach. Moreover, using the persona method allowed us to incorporate the personal and professional backgrounds and priorities of the participants (future UDDT users-operators).

Finally, we introduced the socio-cultural dimension to foster changes to the perception of U's community of an urban UDDT. During both Phase 1 and 2 of this study we noticed that some actors found it complicated to use the dry toilets. In the first year of the project, our diagnosis indicated that the university (urban) community did know what dry toilets were and why excreta should be separated from urine. Also, they did not have practical experience on how to use them. In addition, from the WG2's stay at the ecovillage, we found that women were the most reluctant group to use the dry toilet. These specific and important concerns mean that adoption of UDDTs will require significant public education, gathering of user feedback, and rapid response to their concerns. Overall, considering the environmental, social, and economic aspects designed and built into the UDDT, we can conclude that the intervention addressed the triple bottom line through its sustainable features.

In spaces like Mexico City, it is difficult to introduce new practices related to human waste where water is not a key component. This is partly due to the association between water and disinfection and hygiene (Van Dusen, 2016). Hence, changing the practices of a population, including its habits and customs, requires communication of both technical and practical information, and providing hands-on experiences to resolve biased ideas.

Thus, during the second year, we made significant efforts to engage with U's community through an educational seminar series and the use of online and social media tools for the promotion of the project. We also included multiple design ideas from our community during the co-designing and co-building activities. Future work will focus on expanding the reach of the promotion of this project and developing educational tools for urban communities on topics related to on-site ecotechnologies. In addition, to improve the adoption of the UDDT, future efforts will address the automation of the operator and user interfaces, and the technological development of the accelerated composting and urine microbial fuel cell. Moreover, other ecotechnologies will be sought to be implemented in the LABS' surrounding area (such as an urban orchard, fruit forest and rainwater harvesting) to have a more self-sustaining laboratory space.

The importance of this study lies in having been able to integrate and put into practice various disciplines towards a common project where technology is not separated from the socio-cultural conditions of the population. We combined theoretical aspects of Social Sciences and Engineering to create an innovative interdisciplinary framework and participatory methods for a specific urban space. The University served as a laboratory in which multiple actors came into contact and co-designed and



co-built the project. Moreover, there was a snowball effect that extended the reach of this project beyond U. In other words, our institution could be considered an urban microcosm and our approach used as an example of how these projects could be promoted in other contexts. Overall, this work could provide a benchmark for developing future on-site sanitation interventions for urban SESs in Mexican Cities and help inform interdisciplinary research projects on urban distributed systems.

Based on the results, this study achieved a significant socio-technical transformation within the WG2. We confirmed that socialization of ecotechnologies is a cornerstone for their adoption and implementation in urban communities. Furthermore, we conclude that in contrast to what has been found in other works, there is great interest by urban dwellers in decentralized sanitation. There is therefore a significant opportunity for valorizing human excreta and developing new local economic markets based on processing of this waste. This could not only encourage the acceptance and adoption of on-site ecotechnologies but may help drive the necessary innovation to better adapt them to urban spaces.

Another contribution of this study is the introduction of the involvement of various stakeholders through active participation and deliberation in decision-making, as well as the adoption and maintenance of a novel ecotechnology. Our project elicited enormous interest from all university sectors (professors, students and unionized administrative and maintenance staff). It is worth noting that despite the recent de-prioritization of many sustainability projects at U, the university community has maintained its interest in the LABs and associated activities (elective courses, research work and conferences). Furthermore, the departments involved in the elective courses have continued to offer them at the request of students. Finally, the significance of this research is borne out by the change of attitudes, values, and behaviors within the WG2, as several members actively transferred their experience to other places and spaces within the city.

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