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Design of a Solid Waste Separation, Valuation and Recycling Centre on a University Campus. Case Study

Bethy Merchán-Sanmartín[1,2,3*], Paúl Carrión-Mero[1,2], Sebastián Suárez-Zamora[4], Maribel Aguilar-Aguilar[2], Edgar Berrezueta[5]

[1] Facultad de Ingeniería en Ciencias de la Tierra, ESPOL Polytechnic University, Guayaquil 09015863, Ecuador
[2] Centro de Investigaciones y Proyectos Aplicados a las Ciencias de la Tierra (CIPAT), ESPOL Polytechnic University, Guayaquil 09015863, Ecuador
[3] Geo-Recursos y Aplicaciones GIGA, ESPOL Polytechnic University, Guayaquil 09015863, Ecuador
[4] Independent Consultor, Milagro P.O. Box 091710, Ecuador
[5] Departamento de Recursos para la Transición Ecológica, Instituto Geológico y Minero de España (IGME, CSI), Oviedo 33005, Spain

Corresponding Author Email: maesagui@espol.edu.ec

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ABSTRACT

Waste management is one of the main objectives today as a tool to reduce environmental pollution and ensure the health and well-being of people. The Escuela Superior Politécnica del Litoral (ESPOL) university campus produces around 235.00 tons/year of garbage in Ecuador. In the quest to manage waste, the campus requires an entire infrastructure for its management and sustainable use. This work aims to design a separation, valuation, and recycling centre (SVRC), through technical criteria, for the sustainable management of solid waste. The methodology consists of: i) technical evaluation of the study area to define the SVRC location, ii) design of the collection and transportation route, and iii) architectural, structural, sanitary, and reference budget design of the SVRC. The SVRC structure was designed for an area of 146.37 m^2. This civil work will act as a temporary waste collection centre with a processing capacity of 297.00 tons/year and, mainly, will optimize the volume of waste produced on the university campus, promoting reuse and recycling. Eleven internal routes and one main route were designed for garbage transportation. The methodology used in this study contributes to a solution to solid waste management at the level of universities and municipalities, which can be replicated at the national level.

1. INTRODUCTION

According to World Bank statistics, in 2020, there will be approximately 7,762 million people in the world [1]. Furthermore, based on estimates, the population will probably reach 8.5 billion by 2030 [2]. Accelerated population growth, economic boom, and rising living standards have led to a huge increase in waste generation [3]. However, solid waste generation negatively influences water, air, human health and increases climate change [4]. This situation is of concern in many localities where there is no adequate plan for waste management, representing a danger to human health and ecosystem pollution [5].

Given this problem, integrated waste management represents an efficient alternative for garbage management [6, 7]. Furthermore, this alternative implements environmentally and socially sustainable strategies in solid waste management [8-11]. Disposal management legislation and policies, which are country-specific, determine municipal solid waste collection activities [12]. However, this same legislation promotes a first basic sorting of waste by localities/university campuses at the source.

According to Guerrero et al. [13], local administrations (e.g., municipalities) provide an efficient solid waste management system in cities. However, problems related to the capacity of local administrative authority are common [14], coupled with poor organisation, limited funding, and complexity of the management systems applied [15]. In the case of university centres, with their autonomy in their university campuses, internal management is part of their administration. University campuses are important generators of municipal solid waste [16]. The different activities of the population (e.g., students, teachers, administrators) in these institutions contribute to the increase in resource consumption patterns and, in turn, the effect that their waste generates on the environment directly or indirectly [17]. According to Budihardjo et al. [17], these educational institutions must manage solid waste environmentally friendly, achieving institutional sustainability [18]. There are some cases of higher education institutions that developed waste management plans [19-21], and many of them contemplated that it is essential to generate environmental awareness in students [22]. However, to complement this aspect, it is necessary to have adequate infrastructure for management work [23]. This type of infrastructure integrates activities that enable valuation, treatment, separation, disposal and reuse [24]. Other higher education institutions have included infrastructure for solid waste management. One example is Mahasarakham

University in Maha Sarakham province (Thailand), which has included additional waste management facilities to reduce the volume of disposals going to the local landfill [25]. Another case is the Cesar Vallejo University in the Ancash region (Peru), which implemented a management centre to optimise its solid waste management through a solid waste characterisation study [26].

In Ecuador, there is the National Program for the Integral Solid Waste Management (PNGIDS acronym in Spanish) prepared by the Ministerio del Ambiente (MAE) [27]. Several studies have been carried out for solid waste management in different municipalities in this context. For example, some investigations are oriented toward the importance of organic solid waste as compost for crops [28], considering that one of the productive axes of the country is agriculture. Likewise, the possibility of converting waste into energy through the recovery of biogas has been studied [29, 30], training in rural communities on waste management to care for the environment [31], and the definition of optimal sites for the storage, classification and distribution of solid waste [32]. However, this type of management does not receive the necessary attention in universities, and in many cases, it is not applied rigorously.

The ESPOL university campus, which had a population of 19,032 inhabitants in 2019, produced 168.18 tons of waste, and it is estimated that by 2035 the population will increase to 21,757 inhabitants, so the amount of waste produced will be higher [33]. Currently, the campus has a collection centre that stores the garbage generated. However, this centre is in a place far from the activity area of the campus, which makes it difficult to operate (transfer of waste from collection areas on campus). In addition, it is in an area with no surveillance or control, which leads to manipulation by outsiders. Under these circumstances, it is necessary to have an infrastructure designated exclusively for utilising waste in an appropriate location to optimise waste management.

This study aims to design a separation, valuation, and recycling centre (SVRC) by applying technical criteria following regulations for sustainable garbage management, optimising the volume of disposals, and promoting reuse and recycling.

2. MATERIALS AND METHODS

The methodology consists of: i) Technical evaluation of the study area to define the location of the SVRC, ii) Design of collection and transportation routes, and iii) Architectural, structural and sanitary design, and reference budget for the SVRC (Figure 1). This working method has been designed to comply with current structural and road regulations [34-38] and the processes of solid waste management.

2.1 Technical evaluation for site location

In this first phase, data from previous studies were processed, including analysis of population growth, estimation of per capita production, evaluation of institutional structure in terms of waste management and waste utilisation [33]. In addition, this phase included a geomorphological, hydrogeological, seepage and depression points analysis. For the landslide susceptibility analysis, the Mora-Vahrson methodology [39] was applied, which considers two aspects: a) conditioning factors (geological and geomorphological parameters and slope), and b) triggering factors (seismicity and rainfall). This analysis made it possible to establish a landslide susceptibility map for the institutional campus.

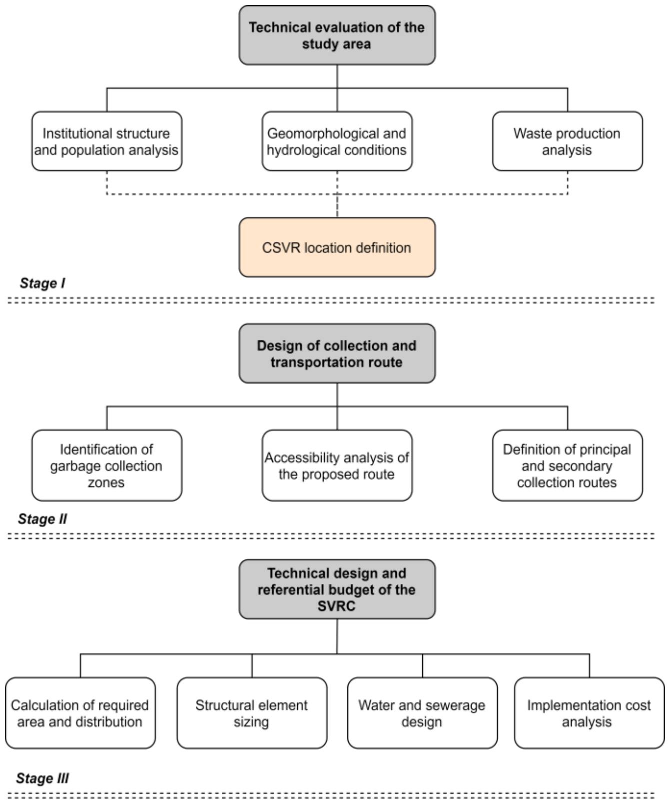


Figure 1. Cavity geometry

For the hydrogeological analysis, the application of vertical electrical soundings (VES) was considered, which allowed the estimation of the type of lithology through the interpretation of resistivities. The points of application of the VES included areas where there is no runoff. The results were processed and interpreted using IPI2win software.

Finally, infiltration and depression points were analysed through a digital elevation model in ArcGIS software to complement the technical evaluation work, covering 50 m under the Ministerio de Ambiente de Ecuador [40]. This analysis made it possible to identify runoff confluence zones to avoid locating the SVRC in areas at risk of water infiltration.

2.2 Stage II: Design of collection and transportation routes

In this second phase, the optimal points were identified for placing non-hazardous solid waste collection areas, where the internal and external routes should be located. It was proposed to place stations with greater collection capacity in these sites to optimise the time spent transporting waste. The sites designated as collection zones were proposed based on collecting garbage cans, distribution of laboratories, research centres, and restaurants.

For the design of the main collection route, the Norma Ecuatoriana Vial Nevi 12 [34] was consulted so that the routes comply with accessibility criteria, do not harm the annual average daily traffic, and the waste transfer time is as short as possible. Furthermore, within the ESPOL campus, the internal routes were interconnected with the collection sites to expedite the work of the people in charge and transfer them to the SVRC through the main route.

2.3 Stage III: Technical design and reference budget

Stage three included the architectural design of the SVRC, considering that it should have the necessary space for waste separation (considering waste generation until 2035), restroom areas, waste containers and the corresponding machinery (such as a compactor, shredder, etc.). The area of the SVRC was determined based on the design of the SVRC of the Universidad del Norte in Barranquilla - Colombia, which has a similar centre. A correlation was established between both universities' population and waste production to determine the SVRC dimensions to be designed in this proposal.

According to the Norma Ecuatoriana de la Construcción in the chapter on seismic-resistant design, NEC-SE-SD [38], for the structural analysis, the Z factor was chosen, which is the maximum expected acceleration in rock expressed as a fraction of gravity, depending on the seismic zone where the project is located. Furthermore, to define the type of live load that the SVRC slab will support, it was chosen to use the values specified in the US code ASCE 7-16 [37], considering that it will not support a high load demand, only its weight and load of people climbing on the deck to perform cleaning or maintenance activities.

The NEC-SE-SD [36] load combinations were used to analyse the most unfavourable condition through a stress envelope in the SAP2000 program to know the magnitude of the stresses generated in the structural elements.

The slab and structural elements, beams and columns, were designed by shear and bending according to the requirements of the ACI 318-14 code [35] and local standard NEC-SE-DS [38]. For the SVRC substructure, a shallow foundation type was designed because the structure does not require high load demands, and the soil is suitable for this type of foundation.

For the potable and sanitary water systems, by the provisions of the architectural plans, the piping design for toilets, urinals, sinks, and showers was carried out using NEC11 [36]. Finally, the budget necessary for the execution of the design, which includes the structural design and sanitary design, was evaluated.

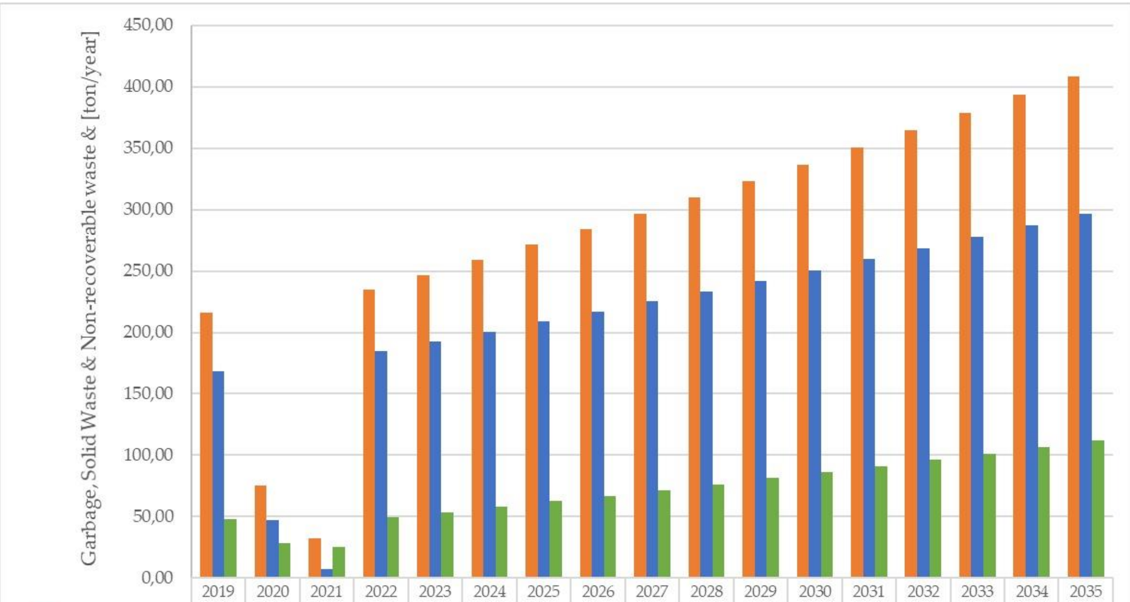
3. RESULTS

3.1 SVRC location

According to Merchán-Sanmartín et al. [33], ESPOL in 2019 had a population of 19,032 inhabitants with a production of garbage that reached 215.82 tons. Garbage composition generated was 61.82% organic, followed by plastic with 18.79%, Then Paper with 13.05%, and the remaining 6.34% is metal, glass, tetra pack, and electronics. On the other hand, the study reflected a growing population projection for 2035 of 23,499 inhabitants. Therefore, the results obtained from the projection of solid waste production until 2035 in this study reach 297 tons/year (Figure 2).

The analysis of the soil conditions in the studied area indicates that due to its morphology (generally gentle slopes) and lithology made up of sands, gravels and shales (Cayo Formation, Cretaceous Period) with a medium-low permeability; the susceptibility to landslides of approximately 85% of the terrain represents stable conditions, propitious for the installation of a SVRC (Figure 3).

Also, within the hydrogeological analysis through 6 VES, it reflects that in the studied area, the resistivities obtained correspond with the lithology as mentioned above, confirming that there is no presence of surface aquifers that affect the implementation of the SVRC in the institution. Based on the information obtained from the ground conditions, it was established that the optimum location for the SVRC is point 6, located inside the university at the Gustavo Galindo Campus, behind the Community Police Unit (Figure 4).



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Garbage	215,82	75,06	32,14	234,60	246,59	258,80	271,23	283,88	296,76	309,87	323,21	336,78	350,60	364,65	378,96	393,51	408,31
Usable Waste	168,18	46,96	7,09	185,12	192,83	200,67	208,65	216,77	225,04	233,44	241,99	250,69	259,54	268,55	277,70	287,01	296,48
Non-Usable Waste	47,63	28,10	25,04	49,48	53,77	58,13	62,58	67,11	71,73	76,43	81,21	86,09	91,05	96,11	101,26	106,50	111,83

Figure 2. ESPOL's annual production of solid waste

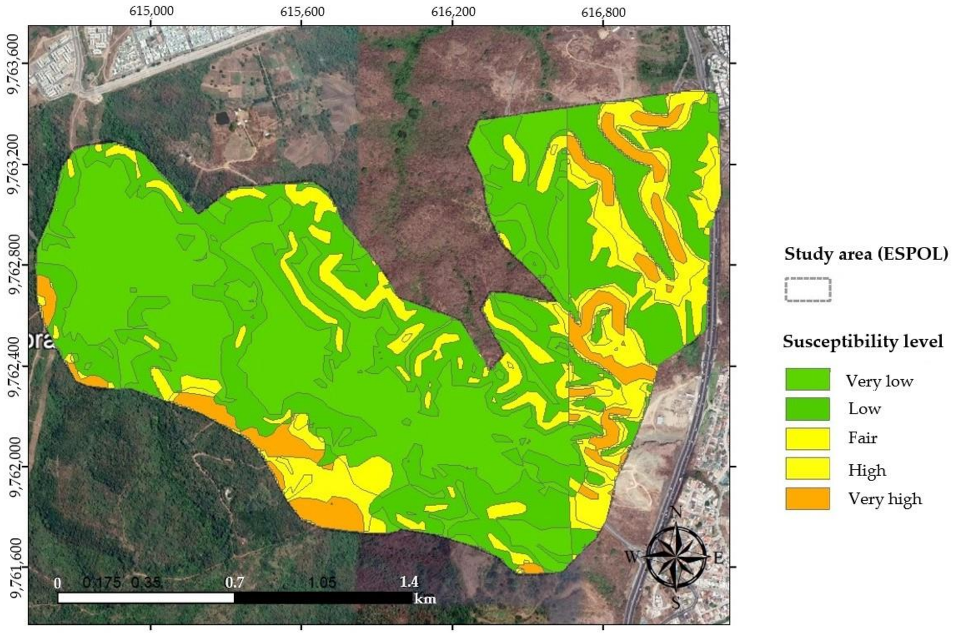


Figure 3. Landslide susceptibility map of the ESPOL campus

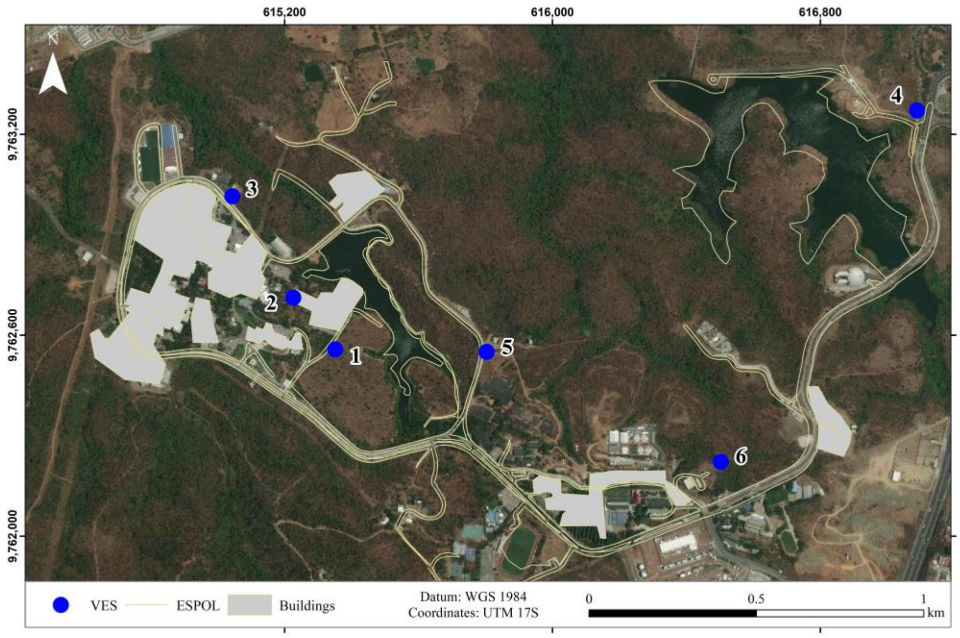


Figure 4. Possible location of the SVRC

3.2 Optimal collection routes

Eleven internal routes were designed to cover the collection sites to transport garbage through the main route. The main route runs through the less travelled area, with a total length of 3,486 m and runs from inside the campus to the admissions building (Figure 5).

3.3 Architectural design of the SVRC

Based on the solid waste projection, the design considered the estimated production in 2035 (Figure 2). The dimensions for the SVRC were 12.30m x 11.90 m, giving an area of 146.37 m^2, with a height of 3.40 m that allows processing from 185 tons/year in 2022 to 297 tons/year in 2035, and can be increased according to the change in the collection frequency of the manager. The centre has five areas: collection area, classification area, crushing and compaction area, weighing area, and toilets. In addition, it has some grids for cleaning (Figures 6 and 7).

3.4 Structural design of the SVRC

According to the NEC-SE-DS norm [38], the structure was designed for soil type D, and a Z factor equal to 0.4 was used. In addition, a portal system was used to design the SVRC. For the design of the reinforced concrete structure, concrete with a compressive strength f'c = 280 kg/cm^2 (28 MPa) and reinforcing steel with a yield strength f'y = 4,200 kg/cm^2 were considered. The live and dead loads supported by the slab are shown in Table 1.

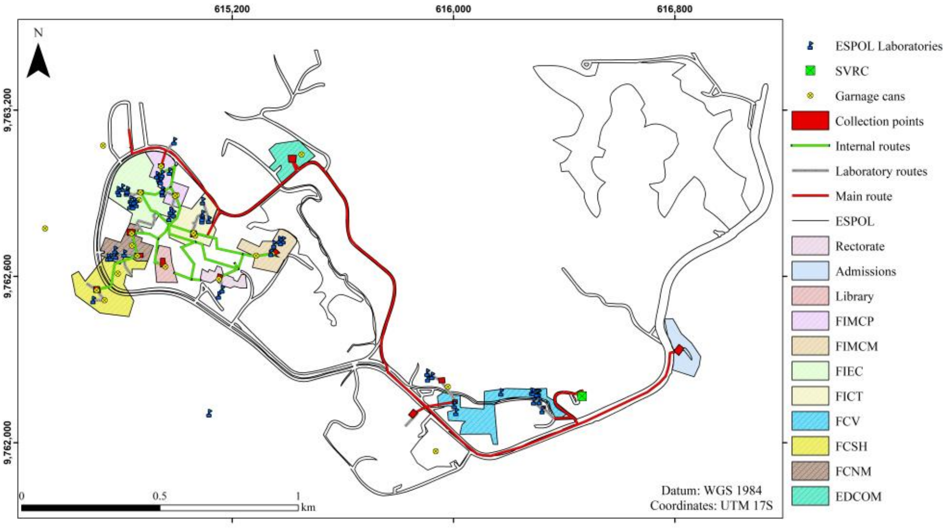


Figure 5. Main and secondary garbage collection routes

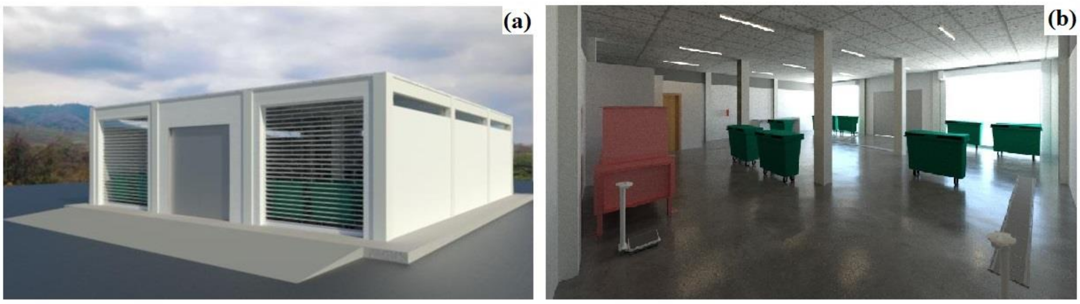


Figure 6. a) Architectural design and distribution of the spaces for the SVRC and b) detail of the interior of the SVRC

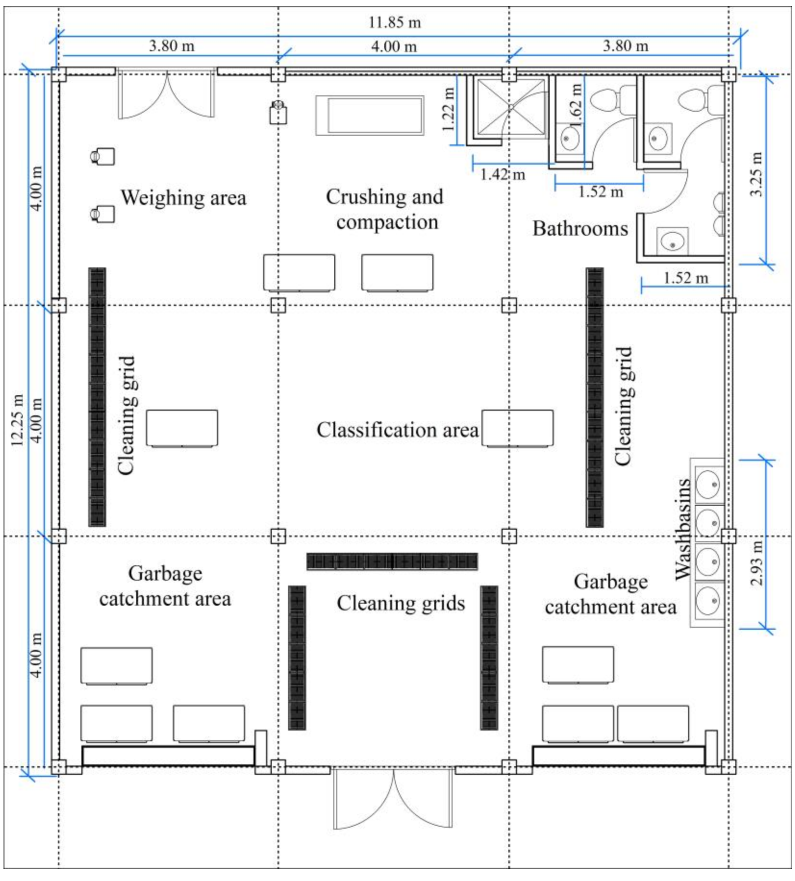


Figure 7. Architectural design of the SVRC and distribution of areas

Table 1. Value of live and dead load to be supported by the slab

Load type	Value	Unit
Live load	0.15	tons/m^2
Dead load	0.50	tons/m^2

Sixteen columns support the management centre slab. Table 2 shows the detail of the columns.

Table 2. Reinforcement detail and column dimensions

Dimensions	b [cm]	h [cm]	L [m]
	30	30	3.40
Longitudinal steel	d_b [mm]		# bar
	12		8
Transverse steel	d_{est} [mm]	#branches	s [cm]
	10	2	10-15-10

Notes: b: width, h: height, L: length, db: bar diameter, dest: stirrups diameter, s: spacing.

The final height of the beams meets the requirements of ACI 318 [35] and NE-SE-DS [38]. On the other hand, considering that columns should be greater than or equal to 25 cm for seismic zones, the beam was designed with a width of b=25 cm. Table 3 shows the detail of the beams.

Table 3. Reinforcement detail and sizing of beams

Dimensions	b [cm]		h [cm]	
	25		30	
Flexural reinforcement	Moment (+)		Moment (-)	
	d_b [mm]	# bar	d_b [mm]	# bar
	12	2	12	3
Shear reinforcement	d_{est} [mm]		s [cm]	
	10		12	

Notes: b: width, h: height, db: bar diameter, dest: stirrups diameter, s: spacing.

The design of the one-way ribbed slab considers a thickness of 20 cm. Figure 8 shows a schematic of the typical slab section.

A 15x20 cm electro-welded mesh was placed on top of the compression slab. Table 4 shows the detail of the slab.

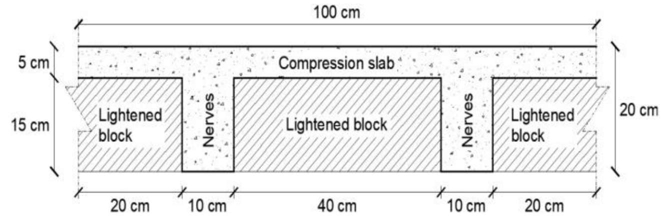


Figure 8. Diagram of typical ribbed slab cross-section

Table 4. Reinforcement detail and sizing of beams

Dimensions	b [cm]		h [cm]	
	10		20	
Flexural reinforcement	Moment (+)		Moment (-)	
	d_b [mm]	# bar	d_b [mm]	# bar
	10	1	10	1
Shear reinforcement	d_{est} [mm]		s [cm]	
	8		10	
Slab	d_b [mm]		s [cm]	
	8		20	

Notes: b: width, h: height, db: bar diameter, dest: stirrups diameter, s: spacing.

The foundation design consists of 1.20 m x 1.20 m insulated plinths, a thickness of 40 cm, and a slab depth of 1.20 m. The reinforcing steel consists of a grid of steel bars, both vertical and horizontal, Ø12 mm in diameter, with a spacing of 15 cm between bars (Figure 9).

3.5 Hydrosanitary design

For the potable water design, polyvinyl chloride PVC pipes were used, with a diameter of Ø ½ inch, while for the sanitation system, PVC pipes were also used, but with a diameter of Ø 4 inches (Figures 10 and 11). It was unnecessary to implement a pump, cistern or elevated tank for this design since the ESPOL pressure has sufficient capacity to supply the entire proposed potable water system.

The work cost estimated based on the price of materials, labour, equipment, machinery, and other activities was USD 1,554.25 for the hydro-sanitary part and USD 27,069.00 for the structural part, for a total of USD 28,623.25.

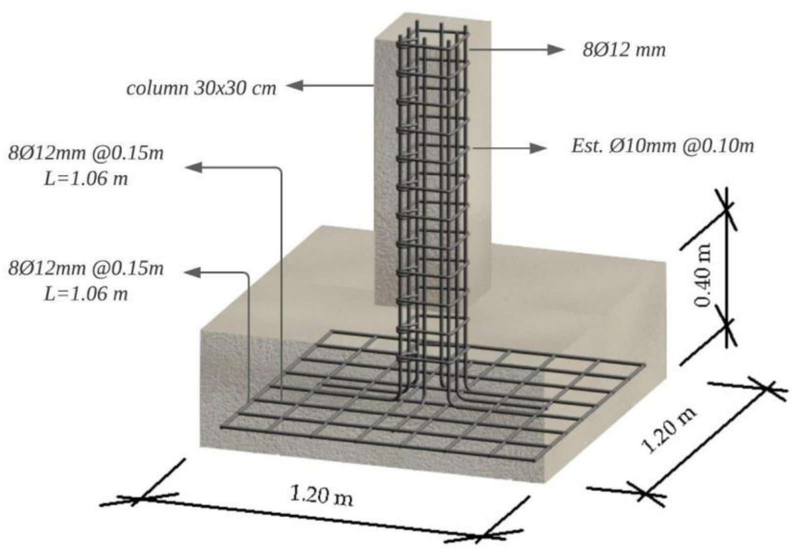
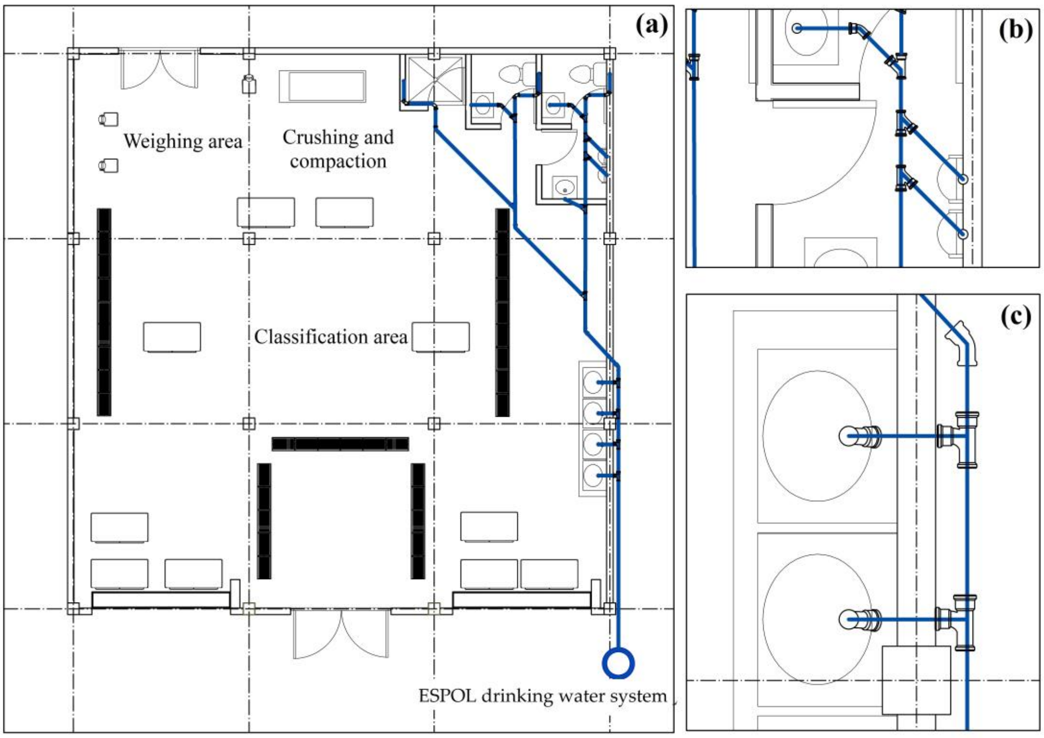
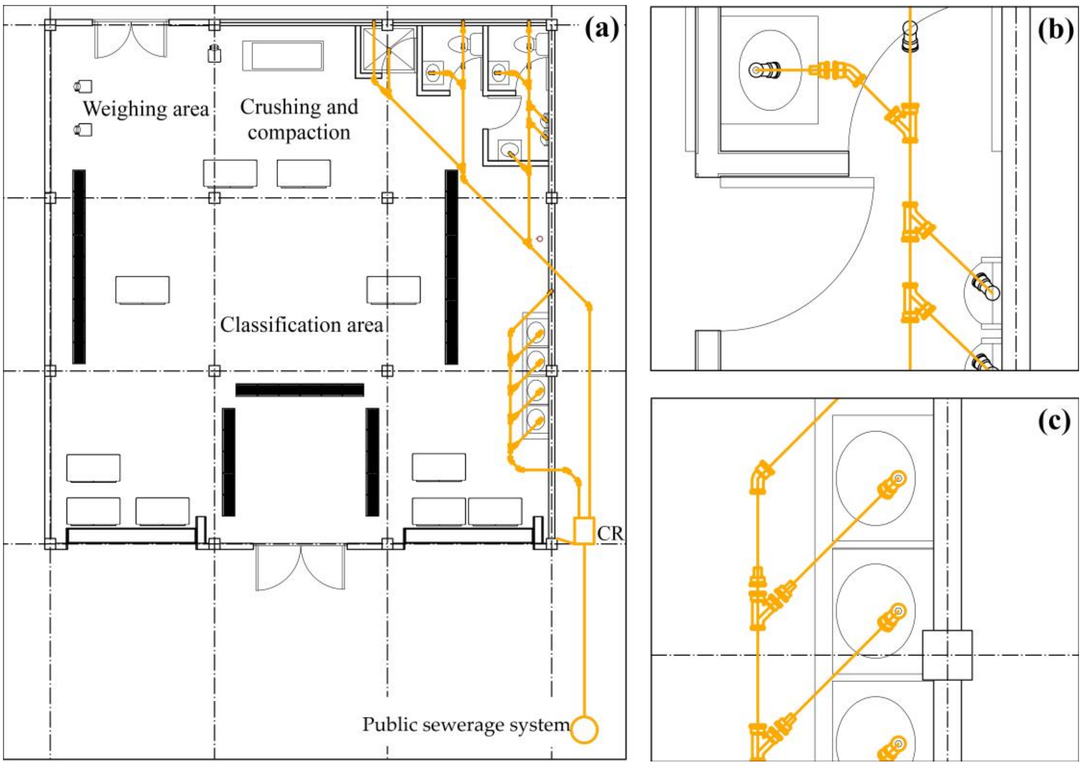


Figure 9. Foundation detail



Note: The blue line is the SVRC drinking water distribution system

Figure 10. Potable water design



Note: a) The yellow line is the drainage system that connects to the maintenance hole. b) CR is the maintenance hole that connects to the public sewer system.

Figure 11. Sanitation system design

4. DISCUSSION OF RESULTS

ESPOL is the leading public university in the country, which provides knowledge and skills to future professionals, making it possible to understand the importance of solid waste management. In a previous study conducted by Merchán-Sanmartín et al. [33], a characterisation of the institution's solid waste was carried out, highlighting a solid waste production of 168.18 tons/year in 2019. Most waste is composed of organic waste, followed by plastic, paper, glass, and metal. According to Armijo de Vega et al. [41], the characterisation of waste (quantity, composition and recycling potential) is essential in management plans.

Solid waste management is one of the goals of the 2030 Agenda for Sustainable Development (Goal 9, 11, and 12). In addition, universities, due to their population, size and activities [42], require waste management infrastructures [43], as key elements for the sustainable development of institutions considered leaders in environmental and social responsibility [44].

Considering that inadequate waste disposal impacts the environment, polluting the atmosphere, water, and soil [45, 46], causing health risks, this study proposes the design for an SVRC with an area of 146.37 m2. The infrastructure allows optimising the volume of solid waste and promoting reuse and recycling. The design of the SRVC has been made taking into account a significant increase in solid waste by the year 2035, which allows for the processing of 297 tons/year, which can be doubled based on the efficiency of the collection and transport plans. Furthermore, decreasing solid waste through separation processes [47, 48], will make successful waste management possible [49]. A one-way ribbed slab type was chosen for structural design due to the low load demand that the slab will support and not require additional economic expenditure for maintenance issues. While for the foundation, having designed it through isolated plinths is justified because the structure sits on firm ground and will not transmit large loads, this is convenient since this type of foundation is more economical due to the low steel demand.

In addition, transport and collection routes have been defined that reduce the distance and time of transporting the waste, representing a decrease in disposal cost. These routes are one of the main components of solid waste management [50]. The total estimated budget for implementing the designed SVRC represents USD 28,623.25, including the structure, sanitation services, and labour, representing a feasible alternative for the university.

This study, which includes solid waste management on campus, makes it possible to determine that liquid waste and emissions into the atmosphere require attention. A future line of research contemplates a plan for liquid waste management through the implementation of purification systems. Likewise, it is recommended to carry out studies to reuse organic solid waste as composting material for the forest and crops within the campus. An essential factor to consider is that the success of this type of proposal is strengthened by awareness campaigns on the correct classification of garbage by the inhabitants, which allows for achieving sustainable waste management.

5. CONCLUSIONS

From a methodological point of view, the study allowed the design of an SVRC for the leading national higher education institution in Ecuador (ESPOL), which strengthens the existing solid waste management plans, promoting a life-cycle culture (circular economy). This design was complemented by defining a main waste collection route that optimises distance and travel time. In addition, this management design promotes an educational, cultural component throughout the university community, whether in curricular subjects for students or in training courses for administrative staff and teachers.

The design of the SVRC is part of the university's integrated waste management. It is located in a strategic sector that contemplates internal routes connected to the main route, allowing waste transfer to a final depot. The processing capacity of the designed SVRC is 297.00 tons/year, which satisfies the population and garbage increase for a period of 15 years.

The methodology used in this study can be replicated in institutions nationwide that lack an SVRC for sustainable solid waste management that encourages reuse and recycling. In addition to this methodology, it is recommended to include a plan for liquid waste management and emission control to reduce environmental pollution problems.

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NOMENCLATURE

cm	Centimetres
m	Meters
kg	Kilogram
mm	Millimetres
cm^2	Square centimetre
m^3	Cubic meters
USD	United States Dollar
Pa	Pascal
m^2	Square meters
tons/year	tonnes per year