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Electricity Generation from Slabs of Construction and Demolition Waste and Waste Electrical and Electronic Equipment

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Many countries depend on electrical energy to be able to develop their activities, and the most advisable is to generate it from renewable energy sources. Construction and demolition waste as well as WEEE (waste electrical and electronic equipment) can be used to generate electricity. Therefore, the research aimed to generate electricity from energy slabs from construction and electrical waste. For this purpose, the waste was collected, sorted and segregated, and then the slabs were made and assembled with the mechanical part. The method of transformation of mechanical to electrical energy arising from the interaction of people through the action of stepping on the slabs was used. The results obtained indicated that a single module of 14 slabs was able to charge a 12 V battery in an average of 4 hours, and by increasing the number of modules the energy collection time is substantially reduced, as long as the flow of people is increasing. Finally, it was concluded that the use of these slab modules is quite favourable for small-scale power generation, provided the necessary conditions are met.

1. Introduction

The urban future has reached an unprecedented level of growth, but it has also led to waste generation. Among them, construction and demolition waste (CDW) as the main gross waste generation stream in modern society (Zhang et al. 2022), and waste electronic and electrical equipment (WEEE) occupying the various types of e-waste generated by the electronics industry (Pan, Wong & Li 2022; Ryan-Fogarty et al. 2023). The global rate of solid waste generation increased from less than 0.3 million tons (Mt) per day in 1900 to more than 3.5 Mt per day in 2010, and will double by 2025 and triple by 2100 (Zhang et al. 2022).
The treatment of CDW and WEEE poses significant environmental challenges (Ryan-Fogarty et al. 2023), and its management stands out due to its hazardousness and complexity. In Colombia, the need has arisen to implement strategies for the reuse of electrical waste in energy generation (Manrique Zarama 2022). Similarly, in Peru there is a series of regulations and laws corresponding to the integrated management system for solid waste generated in all production lines, establishing the need to implement collection centres, treatment plants, dumps for final disposal and safety landfills for hazardous waste (VIVIENDA 2022), and a special regime was established for the management of waste electrical and electronic equipment (WEEE) in order to minimize its generation, and prioritise recovery and valorisation (MINAM 2019).
Many governments fund economic subsidies to encourage the recycling of waste electronic and electrical equipment (Wang, Huo & Duan 2019). Brazil is a clear example to pay attention to as it generated more than 2.26 million metric tons of e-waste in 2021, making it the top e-waste generating country in Latin America and the Caribbean (Statista Research Department 2023). On the other hand, given the growing demand for energy and concern about the non-renewability of primary energy sources, as well as the environmental pollution generated, renewable energy collection systems are chosen as an alternative energy technology worldwide (Chand et al. 2020).

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The literature review shows research on renewable energies that minimize environmental impact (Cruzatt Quispe et al. 2022), waste-to-energy as an alternative energy source (Qureshi, Imtiaz & Jamal 2020), among others (Cabello-Torres et al. 2022; Medina Mori et al. 2022). Nasr et al. (2020) produced an eco-friendly cement mortar containing recycled materials, and demonstrated that recycling waste building materials (marble, granite, and porcelain tiles and clay brick) as a replacement for cement or aggregate in cement mortar can reduce solid waste pollution to the environment, alleviating resource and energy shortages as well as bringing benefits to the economy and society. In the research by Zhang and Xu (2019), they explored new approaches to achieve complete recycling of e-waste with minimal generation of secondary waste, by recycling elements that relate to different types of e-waste.

Thus, the study is justified due to the fact that there is a constant growth in the demand for electrical energy by mankind, which leads to the generation of carbon dioxide (CO_2) in large quantities, making it necessary to search for new environmentally friendly alternatives. Therefore, the use of energy slabs from construction and demolition waste and waste electrical and electronic equipment, applying the principles of circular economy, promotes the transformation of kinetic energy into electrical energy, generating zero carbon dioxide emissions (CO_2). The practicality of this system allows it to be implemented in many areas, for example, at entrance doors, corridors and hallways of shopping centres, universities and schools, as well as at public transport stops, train station staircases, footbridges and in homes.

Therefore, the main objective of the research was to generate electricity from slabs of construction and demolition waste and waste electrical and electronic equipment by determining the energy capacity with respect to the characteristics of the slabs and the number of slabs implemented in the experimental module.

2. Materials and methods

2.1 Collection of construction and demolition waste and waste electrical and electronic equipment

The wastes (Figure 1a and Figure 1b) were collected from the points of generation in the city of Lima, Peru. They were transported to the work area (specialized laboratory) for classification into hazardous and non-hazardous waste, discarding organic waste.

Inorganic waste from construction and demolition went through the segregation and screening process, obtaining a particle size $<$ 5 cm.

On the other hand, from the waste electrical and electronic equipment, some parts to be used were classified and separated according to their functionality in the project. Among these pieces were fan coils or motors, microwaves, power supply cables, integrated circuit boards, remote controls, old radios, among others useful in the project (see Figure 1c).

Figure 1: Wastes collected: a) Construction and demolition wastes; b) Waste electrical and electronic equipment; c) Waste electrical and electronic equipment used

2.2 O Production and assembly of energy slabs

Between 1.5 and 2.5 kg of already processed construction and demolition waste was used to make the slabs. The virgin material was composed of cement and fine sand (<4mm), in the mixing ratio of 1:2. The proportion of virgin material (cement and sand) and CDW was 30/70, 50/50 and 75/25 until the necessary consistency was achieved by adding water, and the mixture was poured and formed into 30 cm x 30 cm wooden moulds (Figure 2a) containing an iron mesh. Subsequently, the obtained slabs were cured by spraying water on their surface at 1, 4 and 24 h of drying.

Once the slabs were obtained, the mechanical part was assembled, which consisted of a mechanical system of pulleys connected to the coils using useful material obtained from waste electrical and electronic equipment. One pulley, one coil and four springs were used in each slab (see Figure 2b).
The slabs assembled with the mechanical part were placed inside a wooden module with a capacity of 14 units placed horizontally, both at the bottom and at the top of the module (Figure 2c). Three modules were used for the experimentation.

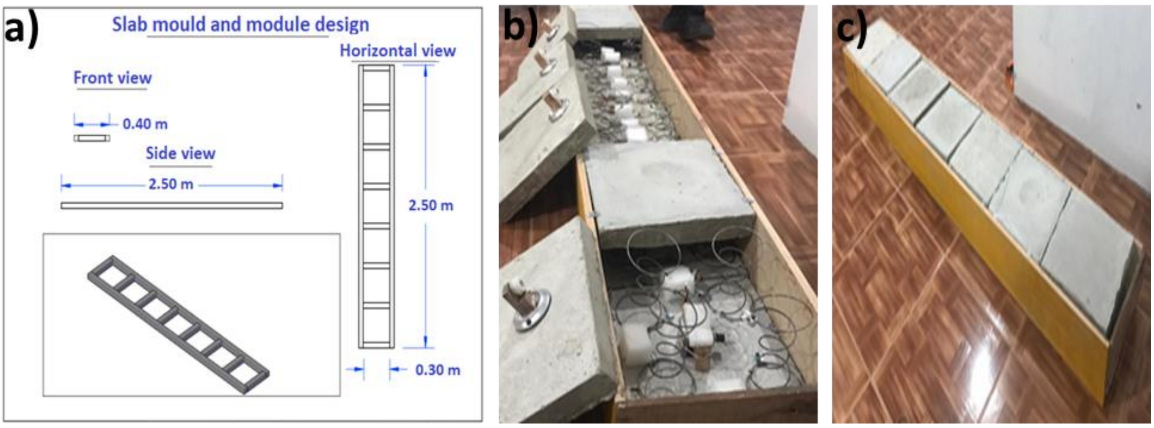

Figure 2: Slab production: a) Slab mould and module design; b) Assembly of the mechanical part into the slabs; c) Module with the slabs connected horizontally

2.3 Module installation and power generation

In the laboratory, the slabs were tested for one week, evaluating the strength of the slab, the functioning of the mechanical system, the generation of electricity and the control station to ensure that they complied with the established parameters before being taken to the field experimentation. The direct current (DC) mechanical generator system followed the procedure of Ang et al. (2019) and Chand et al. (2020), which transfers kinetic energy into electricity.Subsequently, each module with the slabs connected horizontally was installed at the experimental point located at a Metropolitano bus station in the city of Lima, Peru (see Figure 3). The experimentation was carried out during 5 consecutive days starting at 6:00 AM as the starting point, each day considering one module. At that time there is a greater number of passengers boarding the bus, varying from 10 to 65 passengers, which corresponds to the capacity of the bus.The electrical energy generation tests were carried out with a digital multimeter, analysing the amperage and voltage. Each module was adapted to a 12-volt battery, and the experimentation was carried out until the battery was fully charged with the foot pressure of the passengers boarding the bus.

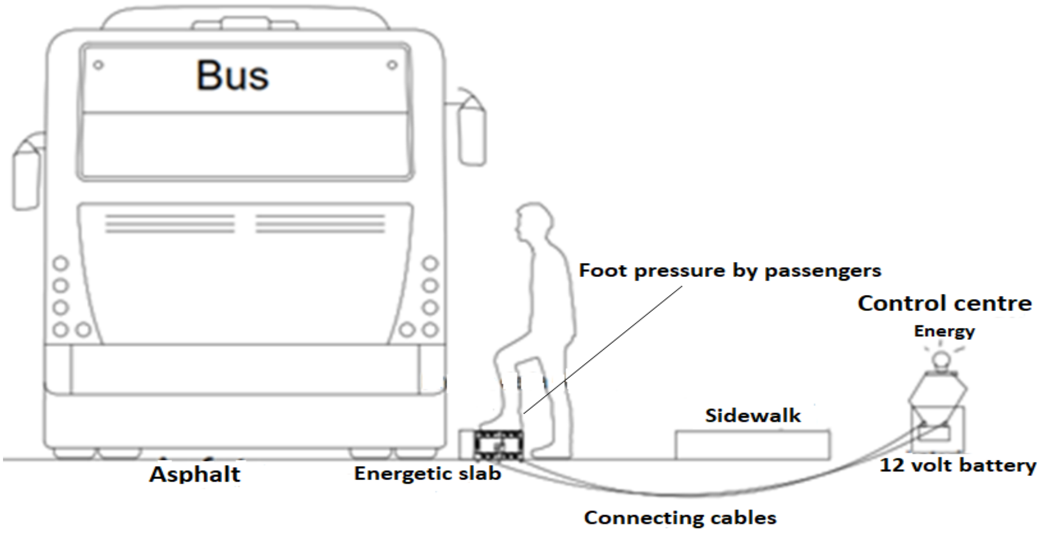

Figure 3: Module installation and electricity generation

3. Results and discussion

3.1 Characterization of solid waste

The solid construction and demolition waste was characterized and classified into hazardous and non-hazardous. Non-hazardous waste included brick (60%), stone cladding (30%), aggregate (5%), tiles (3%) and construction waste (2%). Hazardous waste included grease remover containers, adhesives and paint removal liquids.

3.2 Characteristics of energy slabs

Figure 4 shows the composition of the energetic slabs, the ideal proportion being 25% construction and demolition waste + 75% virgin material. This proportion made it possible to obtain a slab of good consistency for the experiment, with no cracks as in the other proportions studied.

Figure 4: Composition of slabs: a) 70% CDW + 30% virgin material; b) 50% CDW + 50% virgin material; c) 25% CDW + 75% virgin material

The slabs presented small variations in weight due to the characteristics of the material and losses in the pouring and forming of the mix in the wooden moulds. Table 1 shows the characteristics of the slabs obtained that were arranged in the module.

Table 1: Characteristics of the slabs arranged in the module

Upper part of module							
No. of slabs	CDW (kg)	Virgin material (kg)	Total weight (kg)	CDW (%)	Width (m)	Length (m)	Thickness (m)
7	1.50	5.03±0.10	6.08±0.10	24.67	0.30	0.30	0.05
Bottom part of module							
No. of slabs	CDW (kg)	Virgin material (kg)	Total weight (kg)	CDW (%)	Width (m)	Length (m)	Thickness (m)
7	2.50	5.56±0.10	8.06±0.10	31.02	0.30	0.30	0.08

From Table 1 it is observed that the slabs arranged in the bottom part of the module were thicker, and consequently more construction and demolition waste was used in the mix. This is because these slabs support the weight of the system and the passengers boarding the bus, and must have the required strength and consistency.

In the literature, different researches show the use of solid waste as an alternative to reduce and care for the environment. This study is based on taking advantage of construction and demolition waste and waste electrical and electronic for the generation of clean energy, giving it a new use and a new valorisation. Zhang and Xu (2019) proposed the recycling of electronic waste from its elements. In the research by Henrique da Paz et al. (2019), they conducted a diagnosis of construction waste generation in the city of Recife, Brazil, and obtained indicators to improve waste management. Similarly, Jie and Nan (2020) proposed measures for recycling from concrete construction waste in developed countries. For Jiang et al. (2023), to improve construction and demolition waste management, key parameters governing techno-economic and environmental performance should be taken into account, and it is also essential to adopt and expand emerging technologies to increase the added value of materials or products recovered from CDW

3.3 Energy generation

The power generation data is presented in Table 2. It shows the time it took to charge the 12-volt battery attached to the modules containing the energy slabs.

Table 2: Power generation per module

Day	Battery to be charged	Charging time		
		module	2 modules	3 modules
1	12 V	3 h 50 min	2 h 15 min	1 h 22 min
2	12 V	4 h	2 h	1 h 30 min
3	12 V	3 h 30 min	2 h 5 min	1 h 10 min
4	12 V	4 h 20 min	2 h 10 min	1 h 40 min
5	12 V	4 h 15 min	2 h 7 min	1 h 38 min
Average		3 h 59 min	2 h 7 min	1 h 28 min

From Table 2 it is observed that the time to charge the 12-volt battery decreases with increasing number of modules containing the energy slabs. One module charged the battery in an average of 3 h 59 min, while 3 modules charged the battery in 1 h 28 min. This indicates that, with the increase in the number of modules, more area is exposed to the footprint of the passengers boarding the bus, generating more kinetic energy which is converted into electrical energy. Also, the number of passengers boarding the bus must be considered, which is variable for each day of the study and was not controlled.

To use the energy stored in the battery, three 100-watt bulbs were used, giving a value of 5 Amps and the energy consumption or discharge of the 12-volt battery was an average of 3 hours. This shows the usefulness of this system as a source of renewable energy and that it could be installed in places that present the necessary conditions for its operation. In addition, the study demonstrates that alternative clean energy generation is currently being sought, and different countries are studying these possibilities in order to reduce the impact on nature and human life. Chen et al. (2019) indicated that energy generation is affecting the planet and confirmed the need to look for new alternatives that protect the environment, reduce waste generation and provide a healthy and clean environment for future generations.

Other research also shows the generation of energy from renewable sources. Abdul Rahman et al. (2020) proposed electricity generation from the kinetic energy of landing aircraft as a very interesting topic and a necessary initiative to find a new, reliable and viable generation system using free sources. Chand et al. (2020) also investigated renewable, clean and environmentally friendly power generation that harnesses the energy of human locomotion (walking and running). On the other hand, Qureshi et al. (2020) studied the conversion of PET bottles and food waste into plastic fuel. Similarly, Awogbemi and Kallon (2023) reviewed strategies to achieve affordable and clean energy by converting plastic waste into biofuels and other value-added products

4. Conclusions

The research showed that construction and demolition waste (CDW) and WEEE can be used in energy slabs as a source of renewable energy. The slabs had a composition between 25 - 30% of CDW, obtaining the required strength and consistency to support the weight of an average man and also the frictions in the module. In addition, the number of slabs was directly proportional to the generation of electrical energy, observing that three slab modules can charge a 12-volt battery in an average time of 1 h 28 min, and the consumption of the energy stored in the battery lasted an average of 3 hours, using three 100 watt bulbs. This demonstrated the usefulness of the slab system as a source of renewable energy and also represents an alternative for the reduction of waste in the environment and can be installed in sites that present the necessary conditions for its operation.

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