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Valorization and reuse of construction and demolition waste for its transformation into ecological bricks

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ABSTRACT

This research assesses the viability of utilizing construction and demolition waste (CDW) for the production of environmentally-friendly bricks. The methodology employed in this study consists of three main components: An analytical and evaluative investigation of CDW, the selection of appropriate waste materials, and the determination of suitable proportions. The experimental groups were prepared using a volumetric approach, namely Type A (1:6), Type B (1:7), and Type C (1:8), by incorporating CDW, cement, coarse sand, fine sand, crushed stone, confitillo, and polystyrene for the relevant tests. The findings indicate that the optimal composition is achieved with a ratio of 1:5:2 of cement to coarse sand (with 1 part of recycled expanded polystyrene aggregate) and fine sand (with 2 parts of fine sand aggregate) while maintaining a water-to-cement ratio of 1:1. This composition complies with the standards outlined in NTP 399.602:2017, NTP 399.604:2002, and NTP 400.037:2018. In conclusion, the utilization of CDW presents a promising alternative for the construction industry, and effective management practices will facilitate the promotion of a sustainable culture within the sector.

1. Introduction

The construction industry is known for its high consumption of energy and raw materials, resulting in significant waste generation throughout its processes (Galvis and Montealegre, 2019; Guo et al., 2022; Luciano et al., 2022). This excessive waste contributes to environmental issues, including pollution of soil and surface water sources (Aslam et al., 2020; Devaki and Shanmugapriya, 2022; Li et al., 2022). Consequently, many countries have implemented measures to address the comprehensive management of construction waste (Sáez et al., 2014; Hernandez et al., 2015; Pacheco Bustos et al., 2017; Meng et al., 2018; Herrera-Quispe, 2020; Kabirifar et al., 2021; Silva-Urrego and Delvasto-Arjona, 2021; Furrer et al., 2022).

In pursuit of sustainable construction practices, researchers have been investigating the use of alternative raw materials, particularly in the development of eco-friendly concrete (Guzmán et al., 2017; Kumar et al., 2020; Suchithra et al., 2022). Consequently, there have been multiple research proposals exploring the potential of utilizing waste materials for the production of ecological bricks (Guzmán et al., 2017; Ceballos-Medina et al., 2021).

This quantitative research study aims to valorize and assess the feasibility of reusing solid construction and demolition waste (CDW) to produce ecological bricks. The objectives include evaluating the mechanical properties of the bricks, determining the appropriate material proportions for the final product, and examining their technical characteristics.

The project aims to improve and propose cost-effective and structurally sound construction units by manufacturing bricks using CDW. This involves adjustments in concrete mixtures and the utilization of a portable vibrating table.

2. Materials and method

2.1. Production method

2.1.1. Preliminary study of aggregates

The experimental research commences with a preliminary examination of aggregates, which are inert components of concrete that are bound together by hydrated cement paste to form a

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cohesive and durable structure. Aggregates constitute approximately three-fourths of the total volume of concrete, making their quality a crucial factor in determining the final product's properties. Therefore, it was imperative to assess their physical characteristics. In this regard, the study incorporates aggregates derived from construction and CDW, which possess the properties of coarse sand-type aggregates. Additionally, three types of aggregates were utilized, each with distinct granulometric characteristics, namely fine sand, fine sand aggregate 1, and coarse aggregate 1. It is worth noting that Telgopor was also included as supplementary material in the research. Granulometric analysis was conducted to determine the particle size distribution of the aggregates, enabling the selection of materials readily available in a particular area that could yield concrete with satisfactory properties. The granulometric curve served as a useful tool in illustrating the particle size distribution of individual and combined aggregates. A logarithmic plot was employed, as it allows the data points representing the analysis results, obtained through a series of sieves with fixed openings, to form the granulometric curve of the aggregate. The outcome of the sieving process is expressed as the percentage of material retained in each sieve, as demonstrated in Table 1.

As per the Fineness Module (MF) value of 5.02, the coarse aggregate (coarse sand type) is defined as material that passes through sieve No. 4 (4.75 um). The analyzed data aligns with the specified limits outlined in NTP 400.012-2021 (Table 2). The fine aggregate, derived from the natural or artificial disintegration of rocks, passes through sieve 3/8" (9.51 mm) and is retained in sieve No. 200 (74 um). This fine aggregate also adheres to the limits prescribed in NTP 400.012-2021, and this evaluation forms part of the current process, as illustrated in Table 3. Based on the Fineness Module (MF) value of 4.16, the material retained in sieve 4.75 mm (No. 4) is classified as coarse aggregate, meeting the limits established in NTP 400.012-2021. The coarse aggregate utilized consists of natural and crushed gravel, satisfying the specified requirements, as detailed in Table 4. The fine aggregate, obtained from the natural or artificial disintegration of rocks, passes through sieve 3/8" (9.51 mm) and is retained in sieve No. 200 (74 um), confirming compliance with the limits outlined in NTP 400.012-2021. The fine aggregate, referred to as Fine Aggregate Type 2, is depicted in Fig. 1.

Table 1: Granulometric use of CDW

Sieve		Retained (%)	% Accumulated Retention	Pass (%)	% Raisin ASTM standard C 33 fine agricultural spindle
(inches)	(mm)				
3/4	19.00	0.0	0.0	100.0	100
1/2	12.50	6.2	6.2	93.9	100
3/8	9.50	15.3	21.4	78.6	100
Nº4	4.75	34.0	55.4	44.6	95-100
Nº8	2.36	16.0	71.4	28.6	80-100
Nº16	1.18	9.6	81.0	19.0	50-85
Nº30	0.60	5.7	86.6	13.4	25-60
Nº50	0.30	4.4	91.1	8.9	5-30
Nº100	0.15	3.5	94.6	5.4	0-10
Bottom		5.4	100.0	0.0	0

Fineness module: 5:02

Table 2: Granulometric use of fine sand aggregate

Sieve		Retained (%)	% Accumulated Retention	Pass (%)	% Pass ASTM standard C 33 fine agricultural spindle
(inches)	(mm)				
3/8	9.50	0.0	0.0	100.0	100
Nº4	4.75	12.6	126	87.5	95-100
Nº8	2.36	17.2	29.7	70.3	80-100
Nº16	1.18	14.6	44.4	55.6	50-85
Nº30	0.60	14.1	58.5	41.6	25-60
Nº50	0.30	16.4	74.9	25.2	5-30
Nº100	0.15	13.2	88.0	12.0	0-10
Bottom		12.0	100.0	0.0	0

Fineness module: 3:08

Table 3: Granulometric use of the thick aggregate Type 1

Sieve		Retained (%)	% Accumulated Retention	Pass (%)	% Raisin ASTM standard C 33 fine agricultural spindle
(inches)	(mm)				
3/8"	9.50	0.0	0.0	100.0	100
Nº4	4.75	24.1	24.1	75.9	95-100
Nº8	2.36	34.6	58.7	41.3	80-100
Nº16	1.18	15.8	74.5	25.5	50-85
Nº30	0.60	4.9	79.4	20.6	25-60
Nº50	0.30	7.1	86.5	13.5	5-30
Nº100	0.15	6.5	93.0	7.0	0-10
Bottom		7.0	100.0	0.0	0

Fineness module: 4:16

Table 4: Granulometric use of fine aggregate Type 2

Sieve (inches)	Sieve (mm)	Retained (%)	% Accumulated Retention	Pass (%)	% Raisin ASTM standard C 33 fine agricultural spindle
1/2	12.50	0.0	0.0	100.0	100
3/8	9.50	3.1	3.1	96.9	100
Nº4	4.75	6.3	9.4	90.6	95-100
Nº8	2.36	18.0	27.4	72.7	80-100
Nº16	1.18	20.4	47.8	35.5	50-85
Nº30	0.60	16.8	64.5	21.9	25-60
Nº50	0.30	13.6	78.1	12.3	5-30
Nº100	0.15	9.6	87.7	0.0	0-10
Bottom		12.3	100.0		0

Fineness module: 3:18

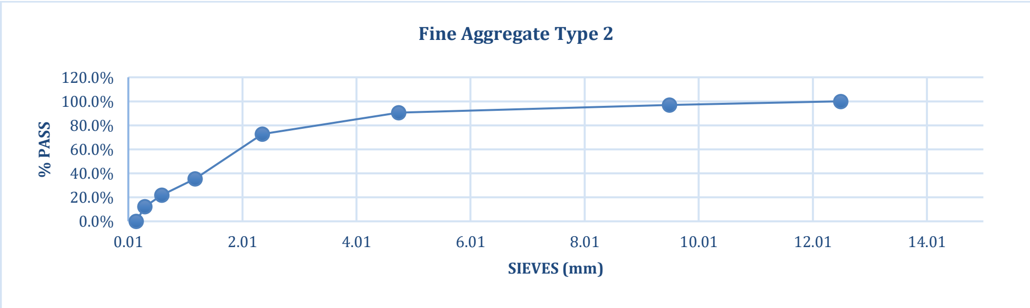

Fig. 1: Fine aggregate– Type 2

Special studies were conducted to determine the optimal combination of aggregates, which is achieved by determining the combination of materials that produce the maximum density compatible with good work of the concrete and a minimum cement content. Table 5 shows precisely what has been executed.

Table 5: Compacted unit weight (PUC) of the aggregate combination

Weight	%	Density
Bucket weight		1102.75
Bucket weight + aggregate		4674.50
Aggregate weight		3571.75
Unit weight	60% sand	1979.06
Unit weight	50% sand	1884.16
Unit weight	40% sand	1917.53
Unit weight	100% sand	1854.77

In Table 5 we can see that the combination of added fine (fine aggregate type 2 and fine sand) 60% and coarse aggregate (CDW and thick aggregate type 1) 40% provides the highest value of the unit weight which guarantees the maximum density compatible with good workability of the concrete.

2.1.2. Specific weight (NTP 400. 022)

We proceeded to determine the specific weight of the aggregates since this acquires importance in the construction when it is required that the concrete has a limited weight. In addition, it is an indicator of quality, in that, the high values correspond to materials of good behavior, while a low weight corresponds to absorbent and weak aggregates. Therefore, it was advisable to conduct additional tests. Applied to aggregates, the concept of specific weight refers to the density of individual particles and not to the mass of the aggregate. The specific mass weight of most common aggregates used is within the limits of 2.6 to 3.00 (Fig. 2).

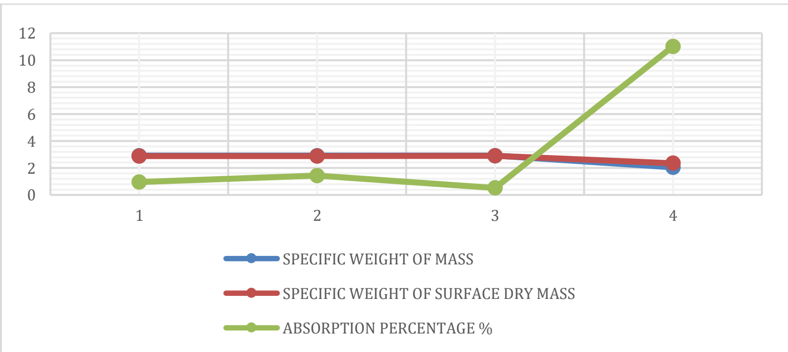

Fig. 2: Specific weight of aggregates

2.1.3. Unit weight (NTP 400 017)

Another process followed was the determination of the volumetric weight or unit weight of the aggregate, this is usually expressed in kilos per cubic meter of material and was required for the aggregates and the dosage of concrete by volume. The results of the trial are set out in Table 6.

Table 6: Unit weight of aggregates

Sample	Loose unit weight (Kg/m$^{2)}$
Added Fine Sand	1796
Thick aggregate Type 1	1396
Fine aggregate Type 2	1639
Aggregate thick Type CDW	1256

2.1.4. Absorption

The aggregates have internal pores, which are known as open when they are accessible to water or external moisture, without pressure requirement, differing from closed porosity, which does not have communication channels with the surface it reaches through low-pressure flows. Absorption is the total internal moisture content of an aggregate that is in the condition of surface dry saturated. This was determined by the increase in weight of a baked sample, and after 24 hours of immersion in water, it was superficially dried. This process was important as far as it allowed us to know the volume of water that the aggregate would absorb in a concrete mixture.

2.2. Physical and mechanical evaluation of the unit

To determine the appropriate dosage that guarantees the specified resistances, a study of the behavior of the blocks in various dosages was conducted. Aggregates with different granulometric characteristics were used. The cement to be used is the most used nationwide: Cements Lima - Sol - Type I.

2.2.1. Resistance tests

After evaluating the quality of the aggregates to be used, the dosage study of the manufacture of the bricks in accordance with the Peruvian Standards NTP 339.600-2017, 339.602-2017, and 339.604-2017 "Concrete Elements" was initiated. Bricks and blocks used in masonry" and satisfying the modular dimensions for walls and partitions, as well as strength and absorption requirements (Table 7).

Table 7: Compressive strength

Samples	Dimensions (mm)			Net area (mm 2)	Maximum load		Compressive strength	
	Longitude	Wide	Height		(kg)	(N)	(Kg/cm^2)	(MPa)
M-1	397	202	192	29474	8100	79461	27.5	27
M-2	395	201	191	28325	5500	53955	19.4	19
M-3	396	202	190	30012	3600	35316	12.0	12
M-4	396	202	191	29652	3700	36297	12.5	12
M-5	395	200	191	28820	8400	82404	29.1	29

Based on the bibliography and past experiences, the study of three dosages in volume is proposed, with a ratio of 30% sand and 30% of coarse aggregate type 1, 10% of fine sand type 2, and 20% of the aggregate of the waste type (construction and demolition waste) and 10% of telgopor as established in the table of proportions (Tables 8-10).

Next, the table of proportions of the different experimental groups carried out in Group-Type A is presented in Table 8, which we have called 1:6, since, the considerations are in proportions of volumes, we have used 1 measure of cement as a pattern, 4 volumes that can be combinations of the different aggregates with the CDW and the Telgopor.

Table 8: Table of group-type A proportions -1:6

Component	I	II	III	IV	V	Saw	VII
Cement	1	1	1	1	1	1	1
Gravel	4			4			
Fine sand		4			4		
Confitillo			4			4	
Coarse sand + fine sand + confectionery							1+1 +2
CDW	2	2	2				
CDW + Telgopor				1+1	1+1	1+1	1+1

I, II, III, IV, V, VI, and VII: Experimental group with different combinations of aggregates

The following data correspond to the mixtures made in Experimental Group II, represented as Type B, and respond to the 1:7 combinations. In this case, we use 1 unit of cement volume and 7 units of the combinations of fine and coarse aggregates with those of CDW and Telgopor.

Table 9: Table of proportions of group-Type B -1:7

Component	I	II	III	IV	V	Saw	VII
Cement	1	1	1	1	1	1	1
Gravel	4			4			
Fine sand		4			4		
Confitillo			4			4	
Coarse sand + fine sand + confectionery							1+1 +2
CDW	3	3	3				
CDW + Telgopor				2+2	2+2	2+2	2+2

I, II, III, IV, V, VI, and VII: Experimental group with different combinations of aggregates

Another proposal was Experimental Group 3 whose proportions are 1:8 and are called Type C. The objective of this group was to include 4 proportions of CDW, 1 unit of cement volume, and 4 units of fine aggregates, coarse or Telgopor.

Table 10: Table of group-type C proportions -1:8

Component	I	II	III	IV	V	Saw	VII
Cement	1	1	1	1	1	1	1
Gravel	4			4			
Fine sand		4			4		
Confitillo			4			4	
Coarse sand + fine sand + confectionery							1+1 +2
CDW	4	4	4				
CDW + Telgopor				2+2	2+2	2+2	2+2

I, II, III, IV, V, VI, and VII: Experimental group with different combinations of aggregates

2.3. Control

To start the experimental process, a Control Group was established that responds to the characteristics that the final product should meet, this is based on the National Building Regulations, Technical Standard E.070 that have as suitable characteristics the following features (Table 11).

Table 11: Type of masonry unit for structural purposes

Class	Up to 100 mm	Up to 150 mm	More than 150 mm	Warping (maximum in mm)	Characteristic compressive strength, minimum in MPa (kg/cm²) over gross area
Brick I	± 8	± 6	± 4	10	4.9 (50)
Brick II	± 7	±6	±4	8	6.9 (70)
Brick III	± 5	± 4	± 3	6	9.3 (95)
Brick IV	± 4	± 3	± 2	4	12.7 (130)
Brick V	± 3	± 2	± 1	2	17.6 (180)
Block P (1)	± 4	± 3	± 2	4	4.9 (50)
Block NP (2)	± 7	± 6	± 4	8	2.0 (20)

(1) Block used in the construction of load-bearing walls; (2) Block used in the construction of non-load-bearing walls

With the results obtained, we verified in what kind of masonry unit our experimental block was to achieve the corresponding characteristics for load-bearing or non-load-bearing walls, which was corroborated with the resistance and compression tests.

In any production process of elements for construction, a series of activities are conducted that are closely related to each other; where the quality will depend on whether these are made in compliance with the established technical requirements. In the same way, each process from the beginning to the end must be organized concatenated, and by clearly defined stages, seeking to conclude in the elaboration of the final product. The project followed the following process: 1. Dosage. 2. Mixing. 3. Molding. 4. Setting. 5. Cured. 5. Drying and storage.

These activities allowed us to monitor and evaluate the results of the experimental part in each of the mixtures proposed in the table of Proportions. So, we have that in the *Type A Group* several of the samples were discarded because they did not meet the required conditions. However, in the mixtures, 1:4:2 = (cement: fine sand: CDW) a good cohesion of the dough was observed that supported by the vibrating, achieves a consistency that facilitates the demolding process. Also, it is observed that in 2 hours there is hardening of the mixture, in 6 hours there is already setting, and the mold has lost moisture more quickly due to the sand component that is a drying material. In 24 hours, the curing of the blocks was conducted for subsequent drying. After 3 days, the manipulation of the block was conducted for the submission of the tests. The same we observed that in the mixture 1:4:2 = (cement: confitillo: CDW) with the difference that in 4 hours a hardening of the mixture was evidenced and in 8 hours there was already a setting. In the mixture 1:4: (1:1) (cement: fine sand: CDW: telgopor) it was recorded that the mixture did present good cohesion and at the time of vibrating it ended with good consistency, after 2 hours hardening of the mixture is evident, in 4 hours the setting was carried out and the mold had lost moisture more quickly. In 24 hours, we proceeded to cur the blocks for subsequent drying. After 3 days the blocks were manipulated, and they were ready for testing. In the mixture of 1:(1:1:2) :(1:1) = (cement: (coarse sand: fine sand: confitillo): (CDW: telgopor) in volume, it was observed that the mixture presents good cohesion of the mass and at the time of vibrating it ended with good consistency and an adequate demolding. After 4 hours there is evidence of hardening of the mixture, in 8 hours it had already set and lost moisture slowly. In 24 hours, the blocks were cured to continue drying. 3 days later, the blocks were manipulated to conduct the tests.

In Group Type B, several of the proposed mixtures were also discarded, highlighting some that passed the test tests: The mixture 1:4:3 = (cement: fine sand: CDW) presented good cohesion and at the time of vibrating, a good consistency. After 2 hours the hardening of the mixture was evident, in 6 hours the set was ready, and the mold showed moisture loss more quickly due to the sand component which is a material of greater drying. After 24 hours, the blocks were cured for subsequent drying. After 3 days the blocks were manipulated and they were ready for rehearsals; The mixture 1:4:3 = (cement: confectionery: CDW); the mixture of 1:4: (2:1) (cement: fine sand: (CDW: telgopor); The mixture of 1:4: (2:1) (cement: confectionery: (CDW: telgopor) and the mixture of 1:(1:1:2) :(2:1) = (cement: (coarse sand: fine sand: confitillo): (CDW: telgopor) showed a good cohesion of the dough and at the time of vibrating a good consistency. After 4 hours hardening of the mixture is evident, in 8 hours the setting is observed, although the mold has lost moisture in less significance because the removal of water from the confectionery is less than that of fine or coarse sand. In 24 hours, the curing of the blocks was conducted for the subsequent drying. After 3 days the blocks were manipulated, and they were ready for rehearsals.

In Group Type C, mixtures 1:4:4 = (cement: coarse sand: CDW) and mixture 1:4:(2:2) = (cement: coarse sand: (CDW: telgopor) were discarded; however, the mixture of 1:4:4 = (cement: fine sand: CDW); the mixture 1:4:4 = (cement: confectionery: RSCD); the mixture 1:4: (2:2) (cement: fine sand: (CDW: telgopor); the mixture of 1:4: (2:2) (cement: confectionery: (CDW: telgopor) and the mixture of 1:(1:1:2) :(2:2) = (cement: (coarse sand: fine sand: confitillo): (CDW: telgopor) presented good cohesion of the mass and at the time of vibrating and demolding ended with good consistency. After 2 hours hardening of the mixture is evident, in 4 hours it had already set and the mold lost moisture. Observing that the sand is the one that allows drying more quickly. In 24 hours, the curing of the blocks and the subsequent drying is conducted. After 3 days, the blocks were manipulated to proceed with the corresponding tests.

The quality control process was continued; 1. Sizing. 2. Warping. 3. Resistance to compression. 4. Water absorption. Verifying in each physical test conducted the dimensioning, warping, resistance to compression, and of water absorption. The observation of each of these stages allowed us to define the characteristics of the final product and proceed to discard some of the samples.

3. Results

Based on the conducted processes and tests, it has been determined that for the verification study of the optimal design, a dosage of 1 part Portland Cement type I to 7 parts of coarse aggregate, fine aggregate, and CDW is recommended. This dosage is applicable for both physical and mechanical property assessments.

The manufactured vibrion blocks, compacted accordingly, meet all the requirements specified by the Technical Standards. Additionally, the 1:7 dosage can be recommended as a standardized design pattern. The proportion of this dosage in terms of aggregate volume is equivalent to using either a ratio of 5:2 (sand to confitillo) or 4:3 (sand to confitillo), as both combinations meet the predetermined ratio of 60% sand and 40% confitillo. However, it is more advantageous to incorporate a larger amount of sand to enhance the texture of the blocks. Consequently, the optimal volume dosage is determined to be a ratio of 1:5:2 cement to sand (coarse aggregate, CDW) to confitillo, along with an initial water dosage of 1:1 (cement to water).

The use of aggregates obtained through the comminution of CDWs for reuse in construction constitutes an alternative that must be considered due to their long-term environmental impact (Guzmán et al., 2017; Ulloa-Mayorga et al., 2018; Gaggino, 2019; Restrepo-Zapata and Cadavid-Restrepo, 2019; Ceballos-Medina et al., 2021; Amarilla et al., 2021; Abera, 2022) for this, awareness, commitment and effective management are important (Kabirifar et al., 2020; Yu et al., 2021). These environmentally friendly, energy-efficient, and cost-effective alternative materials produced from solid waste will show good market potential in different contexts (Ahmad et al., 2017; Abid et al., 2022; Garzón et al., 2022) that enables the application of digital technologies such as modeled building information in CDW waste management (Yuan, 2017; Waskow et al., 2020; Mymrin et al., 2021; Shi and Xu, 2021; Abina et al., 2022; Oluleye et al., 2022; Tan et al., 2022; Wu et al., 2022) and the adoption of the circular economy in the construction industry (Ruiz et al., 2020; Umar et al., 2021; Christensen, 2022; Oluleye et al., 2022; Shooshtarian et al., 2022; Wu et al., 2022; Yu et al., 2022; Zhang et al., 2022).

4. Conclusions

In our environment, there is a significant amount of construction and CDW that negatively impacts the landscape. However, these materials can be repurposed as alternative resources in the production of various products, including our proposed bricks. This approach offers several benefits, such as reducing the demand for new materials and providing the population with sustainable options. By creating employment opportunities and promoting a sustainable culture, this initiative can have a positive impact on the local community.

Based on the aggregate results, it can be concluded that utilizing aggregates with different granulometries may result in an excess of fines. However, this issue can be addressed through proper proportioning and the addition of water to the mixture. The most effective combination of fine aggregate and confitillo was found to be a ratio of 60% sand and 40% confitillo, along with the incorporation of CDW and telgopor. This composition homogenizes the mixture and enhances its density.

Using vibration with the table during the manufacturing process doubles the resistance of the units compared to manual compaction. Additionally, it enables the production of units that meet dimensional tolerances.

The 7-day block strength represents approximately 70% of the strength at 28 days. This allows for quality testing at an early stage and facilitates adjustments to the mixture if necessary.

In conclusion, the produced bricks meet the necessary technical and economic requirements for use in the construction of perimeter fences for low-cost housing. Reusing construction and demolition waste, this approach not only benefits the environment but also contributes to the improvement of degraded areas. Furthermore, it presents an opportunity for tourist areas to undergo landscape recovery and attract emerging tourism.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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