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Soil-Cement Bricks as an Alternative for Glass Waste Disposal

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Abstract

Glass can be recycled an infinite number of times. However, the reverse logistics of bottles, flasks, packaging and others is not always economically feasible, and landfill disposal is widespread in Brazil. The reuse of glass waste is an alternative to recycling, hence the objective of this study was to evaluate the production conditions of soil-cement-glass bricks. The use of glass waste occurred in two ways, one with a cement substitute (glass powder) and another with a soil substitute (crushed glass), in the manufacturing of soil-cement bricks. The results indicated that the glass powder was ineffective in replacing cement. On the other hand, the incorporation of crushed glass significantly improved the mechanical resistance in the specimens. The soil-cement-glass bricks (mass composed of 45% soil, 45% ground glass and 10% cement) molded in conventional and alternative forms showed resistance to the compression established by standards at 14 and 7 days, respectively. This study demonstrated that bricks produced with crushed glass have advantages from the environmental and technical points of view, contributing to the sustainability of the industrial and civil construction sectors.

Keywords: Waste incorporation; Reuse; Ecological Brick.

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1. Introduction

The growth of the global population causes an increasing waste generation, which makes it difficult and expensive to treat and set up its disposition. Waste reuse is a significant action to minimize such problems. The increased costs with raw materials and its reduced availability compels the search for alternative sources of it in the waste and byproducts from many processes and activities. It turns waste reuse into an important tool to sustainable development and environmental conservation [1]. Moreover, they help avoid and postpone waste disposal, as well as reduce problems, such as floods usually caused by the obstruction of drainage systems, and preserving natural raw material reserves. Civil construction generates large amounts of all sorts of waste, besides being responsible for a high consumption of natural non-renewable resources [2]. However, this sector has great potential to absorb solid wastes. Therefore, reclycing waste into aggregates or other components is an important alternative to reduce environmental impacts and to improve preservation. The number of research papers focused on reusing the waste from human activities in construction sites is growing [3,4,5,6]. Results about assessing crushed brick performance as supplementary material in recycled concrete aggregates stabilized with cement have shown that mixtures stabilized with up to 50% crushed bricks as supplementary material and with 3% cement presented appropriate physical properties and resistance consistent with requirements for the highway network [7]. With regard to specific waste such as glass, in Brazil data provided by ABRELPE [8] highlight that glass production reached approximately 3,000 t in 2008; 1,292 t of this total were produced by the packaging sector and 1,280 t by the flat glass sector. The disposal of approximately 20% of the produced packages take place in landfills or some other unknown locations. There is proven feasibility [9] concerning the use of glass waste in different replacement processes (and tested as a large or small aggregate), as well as a cementing agent in bricks, plaster and concrete. Glass from TV tubes and screens has considerable intrinsic strength; it absorbs water and is silica rich. The substitution of sand or pozzolan for glass waste in construction materials is possible, since the characteristics of glass make such substitution feasible [10]. Glass can be a great fine aggregate (sand) replacer in concrete manufacturing, i.e., glass-concrete is more resistant to compression than the standard sample [11]. However, an addition of more than 10% of glass into concrete is susceptible to the expansion of the mixture. Other studies showed that glass addition increased the compression strength by 16%, and the concrete flexion resistance by 14% [12]. Glass waste can be applied to manufacturing ceramic glazes, because glass addition leads to a product with aesthetical and mechanical features similar to the standard glazes, which makes ceramic surface water proof, colored and bright [13]. Besides plasters, bricks and concrete, soil-cement bricks are another alternative to waste disposal. Soil-cement bricks are a soil-cement mixture, and their manufacture is easy, since it occurs through manual molding and it requires neither burning nor expert professionals in its production and use [14]. There are literature reports of waste incorporation in soil-cement bricks. Incorporation of paper and cellulose waste in soil-cement bricks demonstrate that the incorporation meets the normative requirements in terms of compression strength and water absorption [15]. The addition of coconut fiber powder, rice husk and brachiaria bark to soil-cement bricks suggests that the mechanical resistance and water absorption properties are not affected if some of those vegetal wastes substituted cement up to 10% [16]. Results from the use of waste from water treatment plants into soil-cement bricks showed that it helps to reduce the environmental impacts of the water treatment plants [17]. The addition of used foundry sand together with gravel dust reduced water absorption and provided an acceptable level of mechanical resistance, in accordance with established soil-cement standards [18]. In this work we examined the feasibility of recycling glass for the production of soil-cement bricks. We used ground glass as a replacement for cement, and powdered glass as a soil replacement, in the making of soil-cement bricks. It is environmentally reasonable by the use of recycled materials to replace natural resources, contributing to greater sustainability of building materials.

2. Material and methods

The materials used in this research were soils (Red latosol and Yellow latosol), glass waste and Portland cement. There were two kinds of experimental steps. In the first one, we replaced part of the cement with glass powder; in the second one, we tested replacing the soil with crushed glass.

2.1. Glass waste

The used glass was waste of flat glass, obtained from a glazing company located in northern Brazil. It presented big pieces (1 to 20 cm) and it was necessary to ground and sieve into two particle sizes: glass powder (smaller than 0.045 mm) and crushed glass (0.425 to 2 mm). The replacement of cement mass with glass powder to produce test specimens occurred in order to test a possible pozzolanic effect. Cement replacement with glass powder consisted of the following rates: 0, 25, 50, 75 and 100%. Crushed glass replaced soil in test specimens and bricks manufacturing. Soil (red latosol) replacement with crushed glass followed a 50% ratio, in mass. The granulometric crushed glass ranged from 0.425 to 2.00 mm, which corresponds to the mean and gross sand granulometry, since most of the sand in the red latosol was fine sand. According to the technical recommendations, granular soils have a stronger ability to gather with cement [19,20].

2.2. Physical properties

At Table 1 we can see the physical properties of the soils and soil-waste samples. The classifications of soil and soil-waste mixtures occur by granulometric assays and consistence limits (liquid and plastic limits). Soil and soil-waste were classified by comparing these results to results recorded by the National Transportation Infrastructure Department – DNIT [21] that uses the Transportation Research Board (TRB) classification. The Brazilian Portland Cement Association [22] recommends the TRB system. TRB gathers soil groups and sub-groups based on granulometric features and workability. The soil and soil-waste texture are presented in Table 1, based on the NBR 7181 [23] and sand, silt and clay contents.

1 [25]; 2 difference between LL and LP [26]; 3 [27]; 4 AASTHO-TRB adapted from ABCP [22]; 5 based on the TRB classification. * Proportion of ground glass that attributes the best texture characteristics to the soil that receives cement, according to the TRB Classification.

Table 1: Physical properties of the soils and soil-waste samples

Parameter	Soils, waste and mixture types			
	Red latosol	Yellow latosol	Crushed glass	Red Latosol (50%) + crushed glass (50%)*
LL[1] %	17	33	--	17
IP[2] %	Non-plastic	13	--	Non-plastic
Maximum Dry Unit Weight, kN m[3]	18,96	15,44	-	19,40
Optimum Moisture Content[3] %	12	21	--	10
TRB classification[4]	A-2-4	A-6	--	A-1b
Optimum cement[5] % mass	7	12		10
Total sand %	68	27	100	84
Mean and Coarse sand (0.425 <diameter < 4.75 mm), %	4	11	100	52
Fine sand (0.075 <diameter < 0.425 mm), %	64	16	-	32
Silt and clay (<0.002 < diameter < 0.075 mm), %	32	73	-	16

The optimum cement percentage described in Table 1 is a basic recommendation. However, we also tested higher and lower cement contents than the value recommended for the molding of test specimens. For test specimen molding, optimum moisture determination is necessary and occurs by compaction assay, based on the NBR 12023 [24], for cement-free, added-cement and waste-replaced soils. The optimum humidity rates in regards to apparent specific dry mass – which was measured in compaction trials – revealed that the optimum humidity for the red latosol was at around 12%, and at 21% for the yellow latosol. When cement was added, the optimum humidity rates showed no significant change in regards to the cement-free soil. Water works as a lubricant among soil particles. Hence, the surface contact area is larger in soils that have thin granulometry, and more water is required for such lubrication to take place. That is why the optimum humidity for the yellow latosol is higher.

2.3. Test specimens and soil-cement bricks manufacturing

The molding of test specimens occurs in cylindrical molds. After demolded, the specimens had a cure time in humid environment for seven days, according to NBR numbers 12024 [27] and 12025 [28]. At first, we molded test specimens of soil cement with red and yellow latosol, without glass waste. Secondly, for the test specimens that reached the acceptable level of mechanical resistance, we molded test specimens with soil-waste cement. For the soil replaced by crushed glass the used percentage of cement was between 5 and 13%. For the cement replacement by glass powder we molded the specimens at ratios of 0, 25, 50, 75 and 100% in the cement dose that reached the minimal resistance required by standards.

2.4. Soil-cement-glass bricks manufacturing

We manufactured soil-cement-glass bricks in two different ways. At first we molded conventional soil cement bricks. The dimensions of these bricks were 30x15x7.5 cm [29,30], with two holes, molded in the contractor's hydraulic press. The store of bricks were in a humid environment for seven days after molding. A soil-cement perforated brick manufactured (brick with two roles) followed the 50% soil + 50% crushed glass waste mixture and 10% cement, by taking into account the standards and the economic feasibility. Secondly, we manufactured bricks in an alternative form to that specified in the standard, i.e., bricks in dimensions 20x10x5 cm produced in wooden molds. The mixture of soil-cement-waste took place in a concrete mixer, and water was added in order to achieve optimum cement plaster consistency. We then transferred the mixture into the molds and submitted them to slight trepidations in a way as to avoid bubbles. The molds humid cure took place for 24 hours. They were then demolded left in the shadow to cure.

2.5. Compressive strength assay

Test specimens and bricks compressive strength assays happened in accordance to the NBRs numbers 12025 [28] and 8492 [31], respectively, in a universal testing machine at speed 1 mm.min-1. The compressive strength assays took place at the 7th, 14th and 28th day following test specimens and brick molding. Before the compression strength assay the bricks suffered a cut in half (perpendicular to their bigger dimension). The two faces and the cutter faces were reversed and bonded with a thin layer of Portland cement plaster (2 to 3mm thick), according to the NBR 8492 [31]. We immersed the test specimens (for 4 hours) and the prepared bricks (for 6 hours) in water before the compression strength assays.

2.6. Water absorption assay

After the bricks stayed in the stove until their mass was constant, we weighed them. Then we immersed them in water for 24 hours and weighed them again, according to the NBR 8492 [31]. The water absorption calculation occurs using Equation 1.

$$A = [(m2 - m1)/m2]*100 \qquad (1)$$

Wherein, A is water absorption (%); m2 is the saturated bricks mass, expressed in grams (g); m1 is the stove-dried bricks mass, expressed in grams (g).

2.7. Experimental design and statistical analysis

We adopted the completely randomized design for the experiments. The treatments followed a 2x7 factorial arrangement in the cement-ratio investigation stage, two soil types were used: Red and Yellow Latosol, as well as seven traces of cement (5%, 6%, 7%, 9%, 10%, 12% and 13%), with five repetitions. For the test of the effect of cement replacement with powder glass, we investigate five treatments (0%, 25%, 50%, 75% and 100% of cement substitution by powder glass), with five repetitions. Finally, for the effects of aging and brick type on compression strength we followed the 2x3 factorial arrangement, by using two brick types (perforated or massive with alternative molding) at three different ages (7, 14 and 28 days), with seven repetitions. We used analysis of variance (ANOVA) in all inferences. For variables whose ANOVA value was significant ($P < 0.05$), we used the Tukey test or regression analysis.

3. Results and discussion

3.1. Cement replacement by powder glass

Results showed that the higher the glass waste rate, the lower the mean resistance to compression ($P < 0.05$) (Figure 1). Test specimens composed of 75% and 100% cement replacement disintegrated easily after immersion in water. These outcomes evidenced that glass powder did not have the cementing effect on the soil mixture. Replacing cement with glass at 25 and 50% caused the bodies of proof to show resistance to compression, which points out that lower amounts of cement not only were effective, but also promoted better aggregation of soil particles, and it helped keep bodies of proof intact. At the soil replacement amounts of 75 and 100%, bodies of proof initially demonstrated certain stability, but then lost integrity when wetted, since the pozzolanic effect that held the particles together was lost.

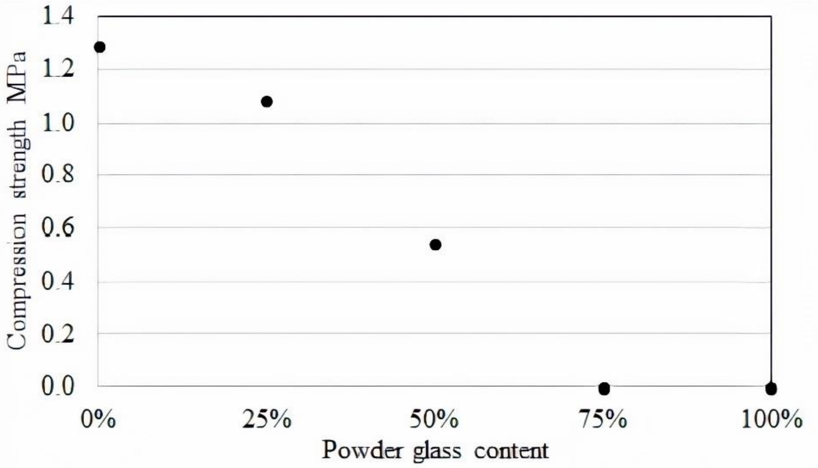

Figure 1: Compression strength in test specimens due to cement replacement by powder glass (Experimental data: closed circles)

Different from records in the current study, some studies point out to the strong pozzolanic effect of glass to enhance cement resistance features in concrete when using cathode ray tube glass as an aggregate [32]. Still, studies demonstrated that the addition of glass powder up to 20% can be used as the replacement of cement to improve the hardened, and long-term properties of concrete like the compressive strength of concrete. Concrete strength decreases with the increase in glass powder replacement due to the smooth surface of glass powder that impedes the adhesion of cement paste and that slows the formation of hydration products due to an increasing percentage of glass powder [33]. The pastes produced with glass powder exhibited a relatively low compressive strength due to very little or no pozzolanic reaction. But the same study showed that increasing the temperature from room temperature to 300 °C can improve the compressive strength pastes. This improvement is mainly attributed to the cement hydration enhancement and acceleration of pozzolanic reaction [34].

3.2. Compressive strength in test specimens with different cement contents

Results of compressive strength applied to test specimens molded for Red and Yellow latosols, with different cement contents, evidenced that the resistance to compression behavior changed depending on the treatment (Figure 2). Variance analysis ($P < 0.05$) pointed out significant differences between soil types. It proved that the Yellow latosol resistance is lower than that of the Red latosol. Large amounts of fine aggregates (like silt and clay, Table 1)) are responsible for weakening the agglutinating effect between cement and the soil. With regard to cement content, the Red latosol (Figure 2) tends to increase the resistance to compression due to the higher cement content ($P<0.05$). The Yellow latosol (Figure 2) tended to increase resistance between contents 6% and 10%, so it remained almost constant between 10% and 13% ($P < 0.05$). The yellow latosol is predominant if compared to the red latosol in the area where we conducted this study. However, due to its texture – which has a high percentage of silt and clay – it is not the optimum soil for manufacturing soil-cement bricks. Even with so-considered high amounts of cement, resistance to compression does not reach the minimum requirements. Based on recommendations in the NBR 8491 [29], the minimum resistance value for the application of sealing elements on walls is 2 MPa. Such value was only accomplished with 13% cement in Red latosol; thus, the cement content necessary to reach 2 MPa resistance is higher than the optimum content recommended by the soil classification (7%) and also higher than the value recommended by the literature as the maximum economically-viable cement incorporation (10%). Higher amounts of cement increase the resistance to compression, but manufacture costs make it unfeasible [35].

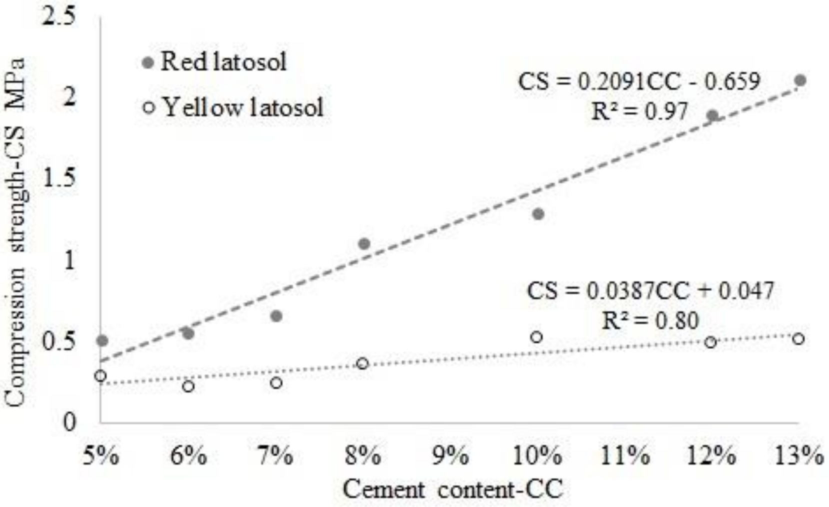

Figure 2: Compression strength in test specimens manufactured with Red and Yellow latosols. (Experimental data: closed and opened circles; regression model ($P<0.05$): dashed lines)

Although cement reacts even with fine soils and tends to stabilize them, the resistance of the colloid/cement structure is significantly weaker than that of the granular/cement structure [19]. Therefore, the presence of silt and clay does not compromise the reaction of cement, but impairs mechanic resistance rates. Clay minerals are attracted closer together during shrinkage and generate hydrogen bridges, which gives rise to increased strength. The process of shrinkage takes, depending on the drying conditions, several weeks until it is completed. In comparison, the crystal lattice of the cement is completed after about 1 day preventing the shrinkage due to their rod-shaped crystals. The clay minerals are not able to interconnect and lose their cohesion [36].

3.3. Compressive strength in test specimens - soil replacement with glass residue

The statistical analysis evidenced the significant effect of cement content on the soil-waste glass mixture compression strength ($P < 0.05$) (Figure 3). Only cement contents above 10% reached minimal resistance to compression 2 MPa. The average resistance to the compression was approximately 50% of the value recommended by the standard (2 MPa) based on the value recommended by the TRB classification (10% cement).

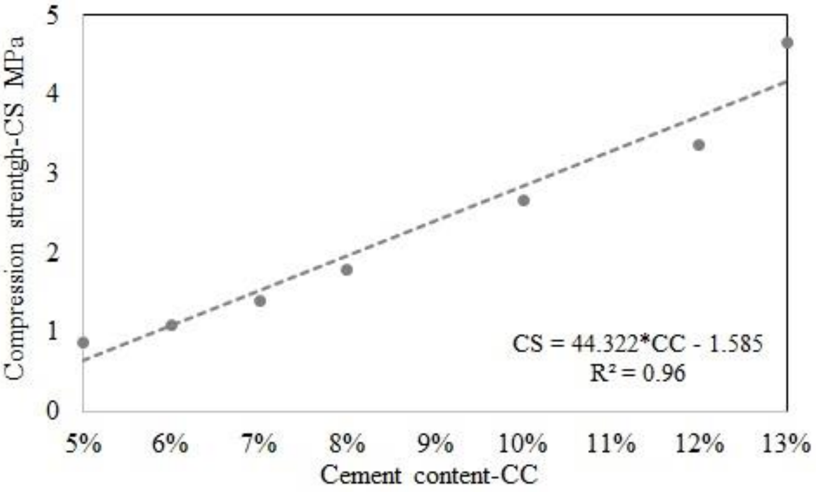

Figure 3: Compression strength in test specimens manufactured with soil and waste (red latosol (50%) + crushed glass (50%)) and cement content. (Experimental data: closed circles; regression model ($P<0.05$): dashed lines)

We observed that a crushed glass incorporation (Figure 3) increased the compression strength of the test specimens (Figure 2). We expected such behavior, since the crushed glass incorporation in Red latosols occurred in order to change the TRB rating, making the mixture fit into class A-1 (Table 1). Soils defined with A-1 characteristics are better for cement stabilization. The change in the rate order points out to a higher amount of sand and a lower amount of fine aggregates. This condition was defined as optimized for the manufacture of soil-cement bricks from the red latosol. Soils presenting very a fine particle size require high cement content because they present higher specific surface; consequently, they also demand larger water volume, which has a negative effect on mixture workability and increases costs [36]. In the process of molding and curing the samples, Moreira and his colleagues [37] observed that the roof tiles incorporated in soil-cement mixtures absorb water that should be used for hydration of the cement; therefore, the strength decreases. Avoiding the use of very fine materials prevent water absorb that should be adopted for hydration of the cement, which prevents chemical reactions from occurring. Therefore, the possibility of incorporating waste into cement-base mixtures is a contribution from civil construction to the recycling of harmful wastes, since it can improve the development of new materials, as demonstrated by Sadek [38] when reusing crushed clay bricks as recycled aggregates.

3.4. Soil-cement-glass mixture perforated brick

The recorded results showed that there was an increase in the average compression resistance of soil-cement-glass perforated bricks against time. The values were 1.72 MPa at day seven, 2.02 MPa at day fourteen and 2.16 MPa at day 28 ($P < 0.05$). The higher compressive strength value than the reference value, 2 MPa, occurred after 14 curing days. The mean compressive strength value was lower than that recorded for assays conducted with cylindrical test specimens. Considering that the produced specimens and bricks consisted of the same contents, the difference between them can possibly be explained by the strength applied to the molds. The strength in bricks pressing was lower than that applied to test specimen molding. Standard rules pose that the manufacture of bodies of proof must obey minimum and specific requirements in regards to pressing conditions, whereas the manufacture of bricks does not require the same amount of energy for the pressing. Age proved to be an important factor related to cement. It’s a relevant factor for the process (Table 2). There was a 25% resistance to compression increase, when 28-day bricks were compared to 7-day cure bricks. Souza; Segantini; Pereira [39] assessed block resistance for 240 days and recorded a 300% resistance gain. Reference [40] found more than 100% resistance gain at the age of 120 days, when the bricks were compared to 7-day bricks [41]. The water absorption of the soil-cement-glass mixture perforated brick presented an average value of 14.5% ± 0.9. It is an appropriate value for this kind of brick (less than 20% water absorption). In bricks, excess water entry makes them heavy, which can prove to be a problem in regards to the resistance of walls, for instance. Besides, the main agents of deterioration require the presence and movement of water within the material itself, so the presence of water can cause damage to the product. Hence, the absorption of the product has a great effect on its durability [42].

3.5. Soil-cement-glass mixture massive brick - alternative molding

The compression strength values were 2.01 MPa at the 7th curing day, 2.09 MPa at the 14th day and 2.29 MPa at the 28th day ($P < 0.05$). Results indicate that massive bricks present higher resistance values than the conventional ones (Table 2). Massive bricks at the 7th curing day presented higher resistance to compression than the values defined in the standard (reference value).

Table 2: Compression strength in perforated and massive soil-cement bricks.

Brick type	Curring time (days)		
	7	14	28
Perforated	1.71 A	2.02 B	2.16 C
Massive	2.01 A	2.09 A	2.29 B

*Means followed by the same letter in the column did not statistically differ in the Tukey test at a 5% probability level.

Assumingly, the two factors were determining to the highest resistance to compression in massive bricks. High moisture content (22,4%) during the molding of massive molding bricks possibly favored cement hydration reactions. Porosity slightly reduced the indices of voids due to the molding procedure and it favored resistance gain. Yet another factor is linked to the physical requirements, since the conventional bricks we manufactured had two holes, which provides more surfaces that are favorable to rupture. However, because molding energy was lower, such difference in mechanical resistance diminished as the curing age advanced. Leonel et a. [18] reported that reduction in mechanical properties may occur due do brick geometries with holes. Water absorption at the 7th curing day was 14.3%±0.1, which was appropriate for values set in the standard.

4. Conclusion

We observed that cement replacement with glass powder did not contribute to a resistance gain in the test specimens, thus, it is not viable as a cement replacement. On the other hand, the 50% soil + 50% glass waste mixture presented the minimum compressive strength at a 10% cement content. The soil-cement-waste bricks presented the minimum resistance required at the 14th curing day. However, alternative brick molding reaches the resistance recommended by the standard at all ages. Both molded-block types present water absorption values below the recommended limits. This study has shown that the proposed brick presents advantages from an environmental and technical point of view, contributing to sustainability in the industrial sector and in civil construction.

5. Recommendations

Recycling of wastes as natural aggregates is not only economically viable but it is also considered an environmentally friendly approach.

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