Assessing the Use of Pine Chip Ash in Manufacturing Soil–Cement Bricks

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1 Introduction

Waste disposal is increasingly regulated and increasingly expensive. Therefore, it is suggested a business perspective on value recovery through reuse of the whole product (Kleindorfer et al. 2005). As Kleindorfer et al. (2005), internal strategies for the future should be focused on investment in capabilities to recover substances causing pollution, to develop substitutes to non-renewable inputs.

The recycling of waste is a prerequisite for sustainability since the generation of waste is inevitable in the industry. The potential benefits of recycling to society are, among others, the preservation of natural resources, energy-saving, reducing the volume of the landfill, reduce pollution, creating jobs, reducing the cost of environmental control by industry, increased durability and even foreign currency economy (Angulo et al. 2001).

Ayres (1989), suggests that companies must find better ways to convert waste from one industry to be used in other sectors. Among these stand out waste mineral ashes from different agro-industrial activities, these, have high percentages of silica and other oxides, which can then be used as a pozzolan. The pozzolan property is its ability to react with the calcium hydroxide released during the cement hydration

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process, forming stable compounds binding power, and silicates such as hydrated calcium aluminates (Oliveira et al. 2004).

This paper fits with the sustainable nature of the approach to Corporate Social Responsibility (CSR). According to Grajew (1999 apud Pinto 2006) CSR is an ethical management of the company, socially responsible in all its actions, in all its policies, in all its practices and relations, whether with the internal or external public of the organization. CSR refers to the objectives above shareholders where the company should take responsibility, including business ethics, ensuring labor rights, environmental protection, the development of philanthropy, donations for public welfare and protection of vulnerable groups. Included, therefore, the financial and economic responsibility, legal responsibility, environmental responsibility and ethical responsibility (Li et al. 2009).

Clark (2007) suggests that an economy can be maintained for sustainable consumption that includes sustainable products and industrial processes. Companies should pay more attention to environmental consequences, supported by public pressure and concepts of the triple bottom line (3BL) (profit, people and the planet), the literal translation of the English, profit, people and the planet (Kleindorfer et al. 2005). According to Kleindorfer et al. (2005), employees need to take pride in their work and they need to believe that their companies operate prudently and responsible to the planet, in addition to worrying about their health and safety.

In this scenario, the article seeks to evaluate the use of pine chips ash in the manufacture of soil–cement bricks, with the center of the problem being the concern about the current fate of these ashes. When will managers stop considering effluents and waste as passive and start seeing them as assets? According to Vaske (2012), wood is still one of most fuels used in some economic sectors of the country, resulting in a high volume of ash that is disposed of without specific control, jeopardizing the water table, contaminating soil and air. The sooner literary contributions address waste management issues, the sooner we will have enough information to prevent, guide, search for solutions and evolve as a whole for the sustainability of the planet.

The soil–cement brick is known in Brazil popularly ecological brick produced by compacting a mixture of cement and sand or various other types of materials such as waste and slag from steel mills, recycled aggregates of building rubble, waste from mining activities and other environmental liabilities arising from various activities (Aniteco 2019). Since they are produced by pressing and do not require subsequent burning, they are called green bricks (Castro et al. 2016).

As a basic premise was considered soil cement bricks fabricate incorporating PCA as an additional material and evaluate the results of its mechanical properties. Would it be possible with the PCA to reduce the use of non-renewable materials and finite in the manufacture of products such as soil–cement brick? The ash is a residue from a plywood industry, derived from burning pine chips. The burning of the chip generates the heating of the boiler waters, resulting in the steam required in the manufacturing process of the plywood sheets. This study deals with the PCA, however, many other industries generate ash, so that material can serve as support for more queries related to waste from other areas. Besides the possibility to study the same ash in several other products. It is important to create opportunities for reflection, with a different look for each and every type of waste.

For better evaluation support was adopted a methodological procedure Product Planning and Development (PPD) identifying details and making use of tools and parameters already certified by the literature. This is intended to characterize the main materials (ash, soil, cement), incorporated in the raw material base of the brick different ash proportions (15, 30, 50%), starting from a formulation already practiced as the proportion of cement, and finally, evaluating the physicomechanical properties of the brick samples according to the current Brazilian technical standard.

2 Theoretical Framework

This applied research was experimental, that to Gil (2008), is to subject the objects of study to the influence of certain variables in controlled conditions and known by the investigator, to observe the results that these variables produce in the objects.

The experiment is contemplated in a sustainable perspective of PPD by Vasco et al. (2014) illustrated in Fig. 1, which shows how much innovation is present in the preparation of a product, and that before the macro environment, integrates environmental, economic and social needs as a parameter for the idealization of processes.

The PDP process of this study was reconciled with the concept of Cooper (1993), who developed the Stage-Gate-process, having a form of stages and steps for review and approve all moments of development. It is a process divided in stages, with pause spaces for contemplation of the results, so-called gates, the literal translation into Portuguese, gates. As shown in Fig. 2, adapted from Cooper (1993), in the stages are made evaluations, investigations, tests and in the gates, decisions are made for the purpose of whether the development of the product passes to the next stage. Three key points were considered fundamental to design a sustainable product: From the idealization with intensified reflections in the detailed investigations (literature review, as this study) and business analysis (analysis and discussion of results, as this study).

The samples were named Samples (A), they were prepared and molded in a hydraulic press with twelve tons of compression capacity (12t.), owned by the same

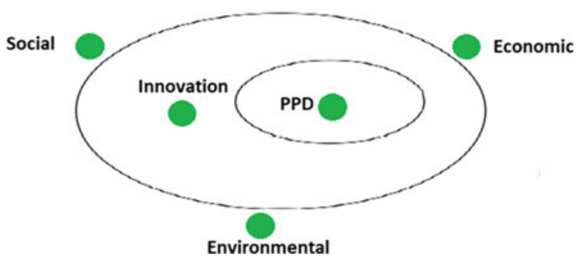

Fig. 1 Perspective PPD sustainable. *Source* Prepared by the authors (adapted from Vasco et al. 2014)

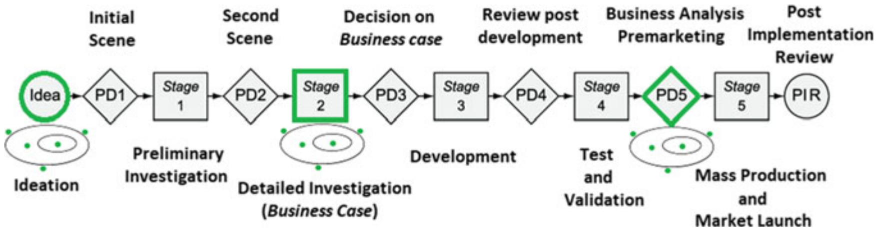

Fig. 2 PPD model. *Source* Prepared by the authors (adapted from Cooper 1993)

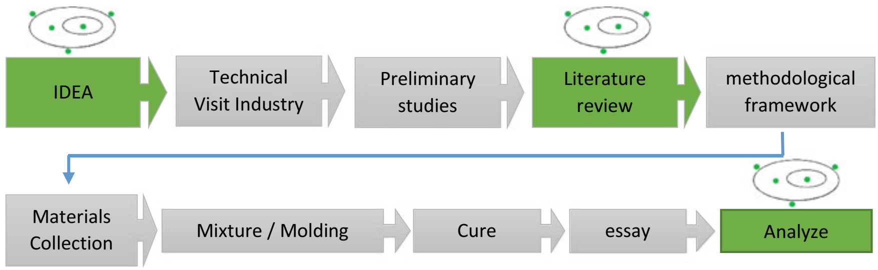

Fig. 3 Flowchart of the PPD. *Source* Prepared by the authors

plant that grantor the soil and cement. The tests were developed in the research laboratory of the Federal University of Technology—Paraná, campus Pato Branco, equipped with a structure that allowed the execution of all the tests prescribed by the technical standards NBR 8491/8492 (ABNT 2012a, b) suitable for floor-type cement cast bricks.

Thus, based on the model of Cooper (1993), PPD procedures for the preparation of samples and testing conducted during the design are illustrated below in the flowchart of Fig. 3.

All flowchart stages were performed, recorded and documented on file for any requests and availability for future demands. The complete material can be important moving forward with the research or even to contribute further assessment on the subject by third parties.

The starting point of the study was on August 30th, 2019 from the preliminary idea to the analysis of the results it took one hundred and five days. The ash in the study is a residue of the industrialization process of plywood sheets in an industry in the city of Palmas-PR, which was previously discussed in the technical visit. Advances have occurred with documentary research for two months to carry out the collection of materials on October 30th, 2019. One day was enough to mold samples and it was patiently awaited the hardening of the cement before performing the tests in the laboratory on December 6th, 2019 the results were summarized and analyzed in the experiment that ended on December 13th, 2019.

2.1 Materials

According to Ferreira and Efren (1984), the most suitable material for producing soil–cement brick is sandy soil (60–80% sand). The soil can be defined as a non-consolidated material on the surface layer of the earth, easily disintegrating, containing various minerals in the forms of sand, silt and clays (Cebrace 1981). The soil used in this study comes from a deposit of sand from the city of União da Vitória—PR, material already used by default in a soil–cement brick factory in the city of Palmas—PR.

Portland cement is a fine powder that has binder properties, which when in contact with water hardens and no longer decomposes when exposed to water again (ABCP 2002). Portland cement is made of clinker and additions, clinker being its main component, present in all types of cement (ABCP 2002). In this study, we used a type of cement sold in some retail stores thus characterized as special, the CP-V type, distributed in bulk directly from the manufacturer to consumers on a large scale. This was provided by the brick factory.

Ash, like the PCA, which is a residue in most cases disposed of as fertilizer on fields by having certain nutrients. However, as Borlini et al. (2005), ash is a waste that even contains metals, those responsible for air pollution and also responsible for serious respiratory problems in the affected population. In the study Borlini et al. (2005), ash showed high amounts of calcium oxide (CaO), silicon dioxide (SiO_2), a certain amount of potassium oxide (K_2O), and also magnesium oxide (MgO). On the other hand, in the way of solutions according to Oliveira et al. (2004), the ash has pozzolan property and should contribute to binding power with similar reactions to cement.

The plywood manufacturing uses pine wood coming from reforestation, therefore considered a sustainable alternative for fence panels, buildings, and other purposes. The industry that cooperated with this research generates 3 m^3 of this residue daily and according to the Remade (2002) in this segment are associated in Brazil about 300 companies, which exponentially increases the total waste generated annually. Therefore, industry factories depend on the proper disposal of the PCA in order to make closed the whole process cycle.

2.2 Method of Water Absorption Test

After the curing period of the samples, the water absorption tests were performed according to the procedures of ISO 8492 (ABNT 2012a). The samples passed through the drying process in the oven at temperatures between 105 °C and 110 °C until the weight stabilized. With the mass density free of water, samples were immersed in a water tank for 24 h. Thereupon, lightly wiped with a towel and reweighed, recording the weight of the saturated masses.

The water absorption values are expressed in percentage and they were obtained by the following equation:

$$A = \frac{M2 - M1}{M1} \times 100$$

Being that:
A = water absorption (%);
M1 = mass of dry brick (g);
M2 = mass of the wet brick (g).

According to NBR 8491 (ABNT 2012b), the average value of water absorption of the samples should not be higher than 20% and the individual values of the samples should not be greater than 22%.

2.3 Method for Compressive Strength Test

To conduct the compression test samples should have seven days or more to cure. They are cut in half, joining the two halves in an overlapping manner and capping with Portland cement paste. After cured capping, occurs the immersion in water for 6 h, which are prepared for disruption, according to the requirements of ISO 8492 (ABNT 2012a).

The compressive strength is expressed in megapascals (MPa), where the value of the maximum breaking load expressed in Newtons (N), is divided by the area of the working face quantified in square millimeter (mm^2) according to the following equation:

$$ft = \frac{F}{S}\,\text{MPa}$$

Being that:
ft = Compressive Strength (MPa);
F = failure load (N);
S = load application area (mm^2).

According to NBR 8491 (ABNT 2012b), the average value of the samples should not be less than 2 MPa and the values of the individual samples should be not less than 1.7 MPa.

2.4 Mixture

The ash went through a screening process in a 4.8 mm mesh screen. Further, all the materials that make up the bricks, soil, cement, and PCA were weighed on a scale 5 g

Table 1 Traces of the mixtures

	Mix Base				
SAMPLE	PCA	GROUND	SAND	CEMENT	ADDITIVE (ml)
A1	0%	100%	0%	11%	0
A2	15%	85%	0%	11%	0
A3	30%	70%	0%	11%	0
~~A4 *~~	~~50%~~	~~50%~~	~~0%~~	~~11%~~	~~0~~
A5	50%	0%	50%	11%	180

Source Prepared by the authors

accurately defining the proportions of trace. For the trace of the raw material called base mixture, it was considered the proportional weight of ash and soil or sand and ash, then the proportion of cement relative to the total weight of the base mixture, as illustrated in Table 1.

For each sample mixtures were prepared independent traces as described, leaving the material in ideal conditions of compaction. Each specific trace was prepared following the same procedures where the components were manually mixed until a uniform mass coloration and good homogeneity. By following a manual mixing process, dry homogenization was initially carried out and only after reaching uniform color was water gradually added to the ideal point for molding.

2.5 Proof Bodies of Molding

The molding is the process of giving the brick format, compressing the mixed material. It has transferred the contents of the first trace to the press and carried out the molding of parts with 12 tons of compression in a hydraulic press, which resulted in visually well-defined parts. Each batch of samples, the cleaning of the equipment was cautiously, avoiding interfering with residues of the previous trace.

The plot called A4* was discarded due to rejection of the ideal conditions for compaction, as it did not present enough agglutination power for molding. The attempt to add the maximum PCA gave rise to the batch A5, replacing the sandy soil (70% sand/30% clay) of pure white sand (100% sand) and 180 ml of the PVA binder additive, named only as an additive. The additive was used for a specific purpose for agglutination due to the absence of clay. According to PISAFIX (2019), PVA has a composition based on Polyvinyl acetate, which is a synthetic polymer, thermoplastic, tasteless and odorless.

2.6 Cure

The healing period is called the time required for the cement action, and for Mehta and Monteiro (2008), healing is nothing more than a set of factors that promote hydration of the cement, especially the humidity, time and temperature, in order to provide material strength. Therefore, the time required for the bricks reaches the point of full resistance. According to ABCP (2002), the cement is partially cured in 7 days and reaches its best performance from 28 days as in Fig. 4. Twenty-eight days was the time considered in the study, before performing the tests.

During this phase, samples were analyzed visually in order to realize inappropriate behaviors such as cracks, blemishes, or other types of faults or changes visible to the naked eye, as shown in Fig. 5.

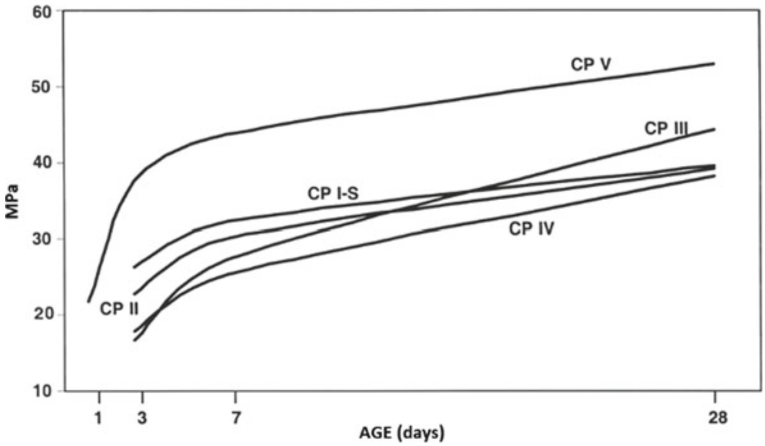

Fig. 4 Age × MPa. *Source* ABCP (2002)

Fig. 5 Samples in curing time/visual analysis. *Source* Prepared by the authors

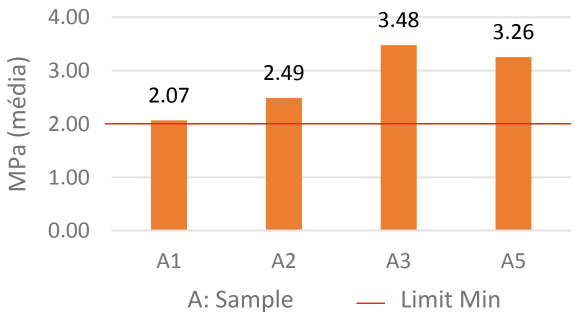

Fig. 6 Results of compressive strength. *Source* Prepared by the authors

The sample A1 has the closest color tone of the natural color of the soil. The small amount of ash added in the sample A2 was sufficient to disfigure the originality compared to the reference sample (A1). It was visually clear the difference that the residue caused in the products.

2.7 Compressive Strength Test

As illustrated in Fig. 6, the sample A1 with 0% PCA showed an average value of 2.07 MPa, the lowest result among all samples, but it is considered acceptable, according to the standard to be higher than 2 MPa. The sample A2 with 15% PCA showed an improvement of 17% in endurance performance with 2.49 MPa. The third sample A3 (30% PCA) recorded an average of 3.48 MPa, a 40% jump from the sample A1. Finally, the sample A5 (50% PCA) averaged 3.26 MPa in its specific trace with additive 36% stronger compared to the reference sample A1 (without PCA).

It is possible to analyze the chart with significant results difference. Because it is the same proportion of cement it is noted that the ash interferes, causing performance improvements in this parameter.

2.8 Water Absorption Test

As illustrated in Fig. 7, the sample A1 obtained 12.08% water absorption, the best result based on the reference parameter that is 20%. The sample A2 has reached 28.41% absorption, followed by A3 25.98%, both by extrapolating the maximum allowable limit. On the other hand, PVA additive contributed to reduced water absorption in the sample A5, even though the greatest amount of PCA it is in this trace. The sample A5 reached 17.92% water absorption, a value acceptable for the commercialization of bricks.

Although resistance has been marked with the PCA addition, the absorption was accentuated in an inversely proportional way in samples A2 and A3. Increasing the

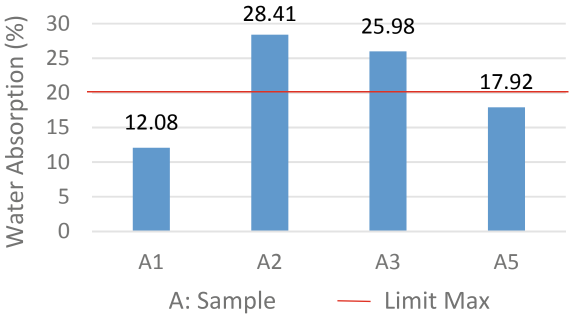

Fig. 7 Water absorption results. *Source* Prepared by the authors

absorption of water is not a good indicator, but it is clear that there is an intensity relation for the dosages of the PCA until a possible balance.

3 Results and Discussion

The sample A1 with the commercial use trace already practiced in the market presents itself in the recommended levels by the standard in terms of the resistance and the best performance and the requirements of water absorption compared with other samples.

Both the samples A2 and A3, despite having the best resistance performances were disqualified for use according to the standard for presenting water absorption indices extrapolated to the tolerable limit for market practice.

Due to the low agglutination capacity of the sample A4, it could not generate molding therefore resulted in no specimen for analysis. The sample A5 was the only one with PCA that obtained consistent rates to the parameters established in the standard recommendations. Its resistance reached 3.26 MPa mark, 38% above the minimum requirement (2 MPa). The water absorption was also within the recommended below 20% for the average determined.

4 Suggestions for Future Studies

There is a need for experiments of the PCA with other types of binders waste such as mud tailings arising from mining activities, as well as disasters already committed (Mariana/MG, Brumadinho/MG) or replacing the sand for the residue of Civil construction and Demolition (RCCD) as well as glass dust, stone dust, and other wastes.

It is suggested further experiments on the PCA diversity of binder waste, replacing soil or sand for Construction and Demolition Waste (CDW) and glass powder, stone powder, among others.

It was restricted to the number of two specimens of average values in the tests. It is suggested further testing with 10 specimens per sample, 7 to break in the resistance test and 3 for the water absorption test.

It is proposed discussion and review of the technical standard NBR 8491, where in item 4.3.5 emphasizes on not discounting the area of the brick holes or the calculation of MPa. One sees a contradiction, given the fact that the item 5.2.1 indicates that the area calculation should be considered by the "Load area". The holes of the bricks are empty spaces that receive no charge, including the practical implementation of the walls.

It is suggested further studies related to the proportion of the traces with the actual density of each material. In the same order to increase the accuracy of results, it is suggested a review of optical microscopy and analysis of broken samples as the uniformity of the mixtures.

It would be of fundamental importance to explore standards indoor wall sealing materials, in order to promote research in the use of PCA product which limits water absorption are more tolerable, or where they are not considered. As the gypsum used for partition walls.

In view of the need to trace additive in the sample A5, there is an opportunity for economic feasibility analysis research, seeking cost parameters with reference to the conventional bricks for comparison.

Study groups have room to explore several variables of the same nuance. The present study provides a simple alternative to PCA, making room for a wide range of experiments with this undervalued waste. To the student's interest, research projects and product development with sustainable nature have numerous tools to support and/or resources.

In short, the branching of study possibilities is illustrated in Fig. 8.

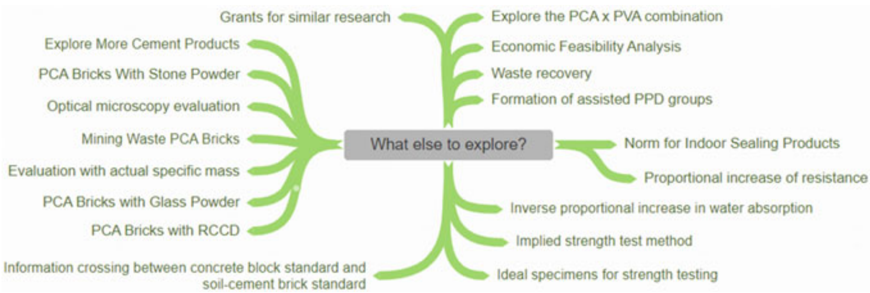

Fig. 8 Suggestions for future studies. *Source* Prepared by the authors

5 Conclusion

This paper generated content supported by sustainability, particularly in solid waste management and in the impact of the environment. Sure, that we are in deficit to the planet, we increasingly produce evidence and solutions to problems. The challenge of being present with this dialogue in daily life and popularize the measures to be taken should be overcome by actions and reports of this kind.

In order to evaluate the use of the PCA in the production of soil–cement bricks, all experimental requirements were implemented topic to topic. The formal record of the tests by laboratory materials allowed the accuracy of the data. The results are even more susceptible to interpretations allowing further analysis. The PCA showed better results with PVA binder additive and pure sand resulting from the washing of the soil of sample A1. In fact, in response to the problem of research, the use of PCA could reduce the consumption of finite materials in the manufacture of soil–cement bricks. Thus, the ashes should not be considered an environmental liability, but rather a raw material with a wide range of possible uses.

The A5 lot was an extra trace, not provided for in the study schedule. However, besides the importance of the aggregate empirical knowledge of the grantor company, there was mutual intention to correct the mixture using an additive, seeking the possibility of using the maximum amount of the PCA. Explored with more dedication new experiences can result in higher quality products.

The convenience to discard in the ground the PCA is still the obstacle to progress. It is primarily up to the managers, as of now, to act with the investigative awareness to solve environmental problems, turning their waste into assets. The way of considering this type of problem as a business opportunity connotes the degree of social responsibility of each organization. We are all responsible for the impacts, already stacked for future generations, so we hope that this content can help similar research with waste in other areas. In addition to the possibility of studying the same ash with other products, the importance of studying all types of waste that we generate is evident.

References

ABCP (2002) Use basic guide Portland cement. Brazilian Portland Cement Association. ABCP, São Paulo, 7th edn. https://solucoesparacidades.com.br/wp-content/uploads/2012/11/28-Guia-basico-de-utilizacao-do-cimento-portland.pdf. Last accessed 10 Nov 2019

ABNT (2012a) Soil-cement Brick—dimensional analysis, determination of the compressive strength and water absorption—test method. Brazilian Association of Technical Standards. NBR 8492. ABNT, Rio de Janeiro

ABNT (2012b) Soil-cement Brick—requirements. Brazilian Association of Technical Standards. NBR 8491. ABNT, Rio de Janeiro

Angulo SC, Miranda LFR, Selmo SMS, John VM (2001) Sustainable development and recycling of the waste in construction. IBRACON, São Paulo

ANITECO (2019) The ecological brick. National Industry Association of Ecological Brick. https://www.aniteco.org.br/o-tijolo-ecologico/. Last accessed 27 Oct 2019
Ayres R (1989) Metabolism in industrial technology and the environment. National Academy Press, Washington, DC
Borlini MC, Sales HF, Vieira CMF, Conte R, Pinatti DL, Miller SN (2005) Gray wood for application in red ceramic part I: ash characteristics. Revista Cerâmica, São Paulo
Castro MEM, Costa FG, Fool SC, Neto EF, Rabelo AA (2016) Evaluation of physical and mechanical properties of soil-cement blocks made with steel products. Matéria Magazine, Rio de Janeiro
CEBRACE (1981) Soil-cement in the construction of schools. Brazilian Constructions Center and School Equipment. MEC/CEBRACE, Rio de Janeiro
Clark G (2007) Evolution of the global sustainable consumption and production policy and the United Nations Environment Program's (UNEP) supporting activities. J Clean Product (Elsevier)
Cooper RG (1993) Winning at new products: accelerating the process from idea to launch, 2nd edn. Addison-Wesley, Reading, MA
Ferreira F, Efren M (1984) Construction with soil-cement. Ceplac, Brasília. https://www.ceplac.gov.br/radar/semfaz/solocimento.htm. Last Accessed 26 Oct 2019
Gil AC (2008) Methods and techniques of social research. Atlas, São Paulo
Kleindorfer PR, Singhal K, Wassenhove LNV (2005) Management of sustainable operations. Product Oper Manag Soc 14(4)
Li ZH, Liu BB, Li CW (2009) Research on the consolidated financial assessment of corporate social responsibility based on fuzzy-AHP. In: 9th international conference on hybrid intelligent systems. IEEE
Mehta KP, Monteiro PPM (2008) Concrete—microstructure and properties material. IBRACON, São Paulo
Oliveira MP, Nobrega AF, Field MS, Barbosa NP (2004) Study of calcined kaolin as partial replacement material Portland cement. In: Brazilian conference on materials and technologies unconventional: housing and infrastructure social interest—Brazil—NOCMAT. Annals ABMTENC, Pirassununga
Pinto LAS (2006) Corporate social responsibility: a reflection on performance indicators. PPGA—University of Taubaté
PISAFIX (2019) Technical bulletin—white PVA Glue. https://www.pisafix.com.br/files/produtos/boletim_29.pdf. Last accessed 25 Nov 2019
REMADE (2002) Evolution points of playwood industry. Madeira Magazine. https://www.remade.com.br/br/revistadamadeira_materia.php?num=193&subject=Pain%E9is&title=Compensado%20aponta%20evolu%E7%E3o. Last accessed 01 Sept 2020
Vasco ODA, Oliveira GA, Santos GD, Bataglin JC, Kummer AA (2014) The management of innovation and product development aluminum artifact companies in Paraná southwest: actions for sustainability. Magazine Industrial Management, UTFPR—Campus Ponta Grossa
Vaske NR (2012) Preliminary study of the feasibility of ash utilization from multi-cyclone type filter is Eucalyptus wood-burning boiler in addition to the fumotubular concrete. Thesis (Doctorate)—Civil Engineering School, Federal University of Rio Grande do Sul, Porto Alegre. https://www.lume.ufrgs.br/bitstream/handle/10183/75712/000883246.pdf?sequence=1 (Last accessed 26 Oct 2019)