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Abstract

This article focuses on the application of recycled gypsum in the manufacturing of 3D decorative wall covering plates and their possible economic and environmental impacts. The gypsum recycling process used in this research consisted in two simple steps: waste collection in constructions and demolitions, and hand trituration. 3D decorative wall covering panels are commonly a composite of cement, sand and gypsum, and they must meet the following requirements: aesthetics, watertightness, thermal and acoustic comfort. Five alternative compositions were made with partial and complete replacement of commercial gypsum by recycling, and a standard composition, with only commercial gypsum for comparison purposes.Two samples were produced for each composition to perform technical-functional performance tests, economic feasibility analysis and subsequent prototype molding. The visual analysis of the plates produced for the tests proved to be favorable in the aesthetic aspect. Following the recommendations of the AssociaçãoBrasileira de NormasTécnicas - ABNT (Brazilian Association of Technical Standards), water absorption and density tests were performed for each sample. The results were satisfactory, presenting to the market three compositions with the use of recycled gypsum, without loss of performance, and up to 38% more economical than conventional. Among the five compositions, three presented a lower percentage of water absorption than the standard. In the environmental issue, it is possible to reduce up to 1 ton of CO_2 emissions per cubic meter produced from the proposed compositions. Finally, the produced 3D gypsum panels meet the sustainability tripod: environmental, economic and social viability.

Keywords: Construction and demolition waste, Decorative wall covering, Recycled gypsum.

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Introduction

Finding ways to reduce waste production in cities has been one of the strongest concerns of modern society, as it is a problem that affects environmental, economic and public health issues. According to a sectoral research report of the *AssociaçãoBrasileira de Reciclagem de Resíduos da Construção Civil e Demolição* - ABRECON (Brazilian Association of Residue Recycling of Civil Construction and Demolition), in Brazil, the final disposal of solid waste still happens in a disorderly way, sometimes through landfills, resulting in floods, pollution, as well as numerous other negative aspects that generate unnecessary expenses for the public finances(ABRECON, 2015).

Conforming to the Brazilian Ministry of the Environment (Brasil, 2016), the construction sector, besides being a major consumer of natural resources and energy, is one of the sectors that generates the most solid waste in the cities. In 2012, Brazil collected more than 35 million tons of construction waste, which represents about 55% of total solid urban waste (Nagalli, 2014). In general, waste from construction is formed during the act of building, refurbishing, excavating and demolishing. Residue of Civil Construction - RCC, or Residue of Construction and Demolition - RCD are generally composed of brick remnants, cementitious materials, sand and metal; And they can amount to more than 30% of all the material used in constructions.

Faced with this aspect, it is possible to observe the necessity to make feasible processes that are linked to sustainability issues, such as reduction of both the material consumption and the waste generated. The Ministry of the Environment recommends special attention for the reduction and adequate final disposition of the RCD, as well as to promote the recycling and reuse of these materials (Brasil, 2016). Thus, it highlights the importance of recycling or reusing some of these residues.

Among the various materials that are part of the residue of construction, it is possible to find some whose reuse is economically and ecologically viable, having gypsum as a good example of this kind of material. Construction gypsum is a generic term for a family of binders that can be produced by the natural gypsum calcination at temperatures ranging from 100 °C to 180 °C, accepting a total impurity of up to 6% (Bauer, 2000). After the advances of technologies, studies related to gypsum recycling showed the feasibility of the practice and explained the processes by which the residue must pass to have a similar performance to the original, which basically consists of trituration followed by a new calcination.

According to Melo (2012), if compared with conventional binders used in construction, such as lime and Portland cement, gypsum can be considered a material of optimum environmental performance. While the production of lime and cement requires a calcination with temperatures between 700°C and 1400°C respectively, gypsum can be obtained under relatively low temperatures, around only 150 °C as mentioned. It is noteworthy that the first two binders in their manufacturing process release CO_2 into the atmosphere, while gypsum releases only water vapor. Thus, the diffusion of the use of gypsum as a construction material will be beneficial to the Planet Earth. However, because it contains sulfur in its composition and is easily soluble in water, its residues are harmful if released directly into the soil.

Gypsum residues used in construction, when improperly disposed, can lead to the release of hydrogen sulfide (H_2S), contributing to soil and groundwater contamination, depending on the region (Zanta et al., 2013). Therefore, elaborating constructive processes that encourage the reuse of this material could avoid problems caused by its inadequate disposition, also delay the gypsum deposit depletion, and even reduce its waste volume.

According to Pinheiro (2011), about 60% of the annual natural gypsum extraction in Brazil is directly used in gypsum consumption for the application in construction. Due to its binding characteristics, gypsum is applied in several ways in the building industry, such as wall coverings, ceiling, plasterboards and precast components. Another application that is gaining more visibility in the market is 3D decorative wall covering plate, which is a mixture of cement, sand and gypsum (in greater proportion), and it can be used in external and internal areas.

The 3D decorative wall covering gypsum panel is a contemporary style in interior decoration that brings elegance and sophistication to the environment. It is a system of gypsum plates that, when joined together, form a uniform panel with a custom effect. It can be applied in homes, stores, hotels, offices, and others.The difference between the common plaster and the 3D gypsum panels is in the visual and aesthetic effect. Since the former gives extra dimension to the walls, ensuring a different, fancy and modern look to any room.

This research focuses on studying the feasibility of the reuse of gypsum residue from construction or demolition in the manufacture of 3D decorative panels that meet the technical requirements for the market, analyzing its possible economic and environmental impacts.

Gypsum Residue and its Recycling Process

Gypsum has characteristics and properties that give the material a great potential for recycling and reuse. However, the gypsum residue was considered by the ConselhoNacional do MeioAmbiente (Brazilian Environment Council) - CONAMA (Brasil, 2002) a class C waste, without viable technology for recycling, and only in 2011 through its resolution 431 (Brasil, 2011), gypsum residue was transferred to Class B, which are recyclable residues to other destinations, such as plastics, metals and gypsum. Thus, the data acquisition on the generated gypsum waste and what are its main characteristics is extremely important for the development of mechanisms that allow its application with acceptable performance.

As reported by Pinheiro (2011), the formation of gypsum residue occurs both in the initial processes of its manufacture (extraction, production and processing) and in the procedures for construction and demolition. In Brazil, where the use of plasterboard is still not as significant, it is estimated that the gypsum residue volume varies from 1% to 15% of the total RCD, depending on the region. The same author shows that gypsum residues can reach 35% of the total volume applied in construction, distributed in theTable 1.

Table 1. *Estimative of the Gypsum ConsumptionandResidue Generation in Brazil*

Gypsum consumption and residue generation	Sector		
	Covering	Plasterboard	Components
Gypsum consumption	35%	14.3%	46.7%
Residue from casting*	-	2.5%	Data not available
Residue from construction*	36.25%	12%	Data not available
Residue from Demolition	Incorporated into other materials	Data not available	Data not available

*Percentages based on the Gypsum Mass Consumed by the Sector. Source: PINHEIRO (2011).

Several countries around the world have been practicing gypsum recycling for years, and some have specialized companies, for example Gypsum Recycling International, which operates in 9 countries. In its virtual brochure, the company shows how is its recycling process for drywall plasterboards on an industrial scale, and it brings some benefits that the practice allows, such as the fact that each recycled gypsum ton represents a reduction of200 kg of CO_2emission into the atmosphere (Gypsum Recycling International, 2016).

The Brazilian standard NBR 10004 (2004) classifies gypsum as non-inert residue due to its sulphate nature and high solubility. The material must have a final destination in appropriate areas, ensuring that it is able to avoid contamination of soil and groundwater, with increased acidity and sulfurization of the environment.

The final deposition of gypsum waste in common sanitary landfills is not recommended. The humid environment, associated with the aerobic conditions and the presence of sulfate reducing bacteria, allows the dissociation of gypsum components in carbon dioxide, water and hydrogen sulphide (H_2S), which has a characteristic odor of rotten egg, also it is toxic and flammable. The incineration of the residue produces sulfur dioxide (SO_2), a very toxic gas.

However, Pinheiro (2011) points out that, despite being considered a recyclable waste, there are almost no gypsum recycling factories in Brazil, and its destination continues to be a problem due to the fact that it is not accepted in landfills for the reasons explained above and sorting areas appropriated to final disposal are rare.

The gypsum residue recycling processes can be performed in a simple way through trituration and/or trituration associated with calcination. However, some precautions need to be taken during the process, such as proper waste management to minimize the contamination and remove impurities as paper, for example (Melo, 2012).

In this research, it was tried to use a simpler recycling process since the proposal is to use this material in the manufacture of 3D decorative panels, something that in the region is still produced in an archaic way. The used process involved only two steps: collection in constructions and demolitions, and manual trituration.

3D Decorative Wall Covering Panel

Highly rated on the market, wall covering panels, or plates, with 3D effects have increasingly become part of the current buildings. This type of material has been pleasing professionals in the area to function as a durable decoration element, replacing wall papers and fabrics, and they can also be applied to outside walls or facades (Athas, 2016).

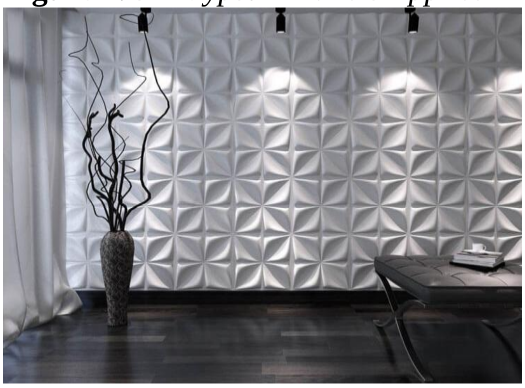
Three-dimensional decorative panels are commonly derived from the combination of gypsum, cement, sand and water. In general, the manufacturing process is simple and basically consists of mixing the materials in a systematic way. Thereafter, the compound is placed in the mold, generally made of silicone, after a short time, it can be removed.

The company DECOR3 - Decorative Wall Covering specialized in the manufacture of 3D gypsum panels affirms that the panels have a great thermal and acoustic insulation and can be used in internal and external areas. The difference between conventional gypsum board and 3D gypsum board is merely visual and aesthetic, and the combination of the 3D panels components allows their application in external areas.

The 3D panels are designed for when attached to the wall, side by side, they will form a geometric pattern in three-dimensional aspects. The panels are very versatile because they can be installed on various flat surfaces, such as wood ceiling, ceiling, doors, drywall, plaster, tile or cement. In addition, it is possible to take advantage of the panel's light weight to install in places where the wall would not support the weight of a traditional porcelain plate. However, the most attractive of all the 3D panels characteristics is undoubtedly its beauty.

The 3D gypsum panels can be found in countless shapes, for example with floral designs, straight, wavy, orthogonal, eclipse, pyramid, star, among others.Figure 1shows a particular format applied in an internal environment combined with lightening effects.

Figure 1. *3D Gypsum Panels Applied in an Internal Room*



Source: Construindo Decor (2016).

Due to the lack of standards, the technical feasibility study of 3D decorative panels with addition of recycled gypsum was conducted in a comparative method, using a 3D panel (conventional on the market) as the standard of analysis and the established requirements were: aesthetics, watertightness, thermal and acoustic comfort.

Methodology and Materials

Aiming at the production of decorative wall covering plates with the insertion of reused gypsum in its composition, procedures were established for collection, recycling and application of the residue.

For the determination of the physical properties of gypsum powder for civil construction, the Brazilian standard NBR 12127(1991) was used, which prescribes the methods and procedures to determine the granulometry and unit mass. In addition, the NBR standardizes the recommended tools, the procedure in which samples are prepared, the technical tests and how to obtain and present the results.

Following the recommendations of the Brazilian standard NBR 12128 (1991), it is possible to carry out the methods to discover the physical properties of gypsum mortar. This standard includes the determinations of normal consistency and setting time.

The Brazilian standard NBR 12129 (1991) shows which is the recommended method to determine the mechanical properties of gypsum for construction, which are hardness and compressive strength.

It is observed the requirements for receiving gypsum to be used in casting and coating according to the criteria of the Brazilian Standard NBR 13207 (1994). In this standard are fixed the general and specific conditions, requirements, inspection, acceptance and rejection of gypsum for use in civil construction.

Procedures

<u>Collection</u>

The collection was made in residential constructions in the city of Palmeira dos Índios, state of Alagoas, Brazil. The residues were separated by the workers and stored in sacks, which were transported to the Construction Materials Laboratory of the Federal Institute of Alagoas – IFAL, Campus Palmeira dos Índios.

The gypsum components used in construction are generally pre-cast parts used for ceilings boards, or for partitions and walls. The productive chain of these parts can be mechanized or manual, consisting of the steps of preparing the mortar, forming and drying.

The mortar preparation is carried out by mixing gypsum and water, and may contain additives and additions necessary for the performance of the desired product; The forming process uses special molds, which provide the product with specific shapes and dimensions, and drying can be performed outdoors, in protected environments or in special greenhouses

During transportation and application of the pre-cast components, there are breaks and losses, causing localized or general damages that require the disposal of the parts. These are some of the reasons for waste generation in the application. In addition, there is also a large volume generated in the production chain of the pieces.

The collection consisted of both residues in the production chain and in the final phase of application of the pre-cast components.

Recycling

The reversibility of the transformation reactions of crude gypsum ($CaSO_4$) in gypsum for construction (calcination) and gypsum in gypsum dihydrate (hydration) makes it possible to recycle the residue. This recycling process may be by trituration only or trituration associated with calcination in ovens with temperature controlled. However, such a procedure requires a higher degree of investment and productive techniques, avoiding the scope of work, which only proposed to reuse gypsum.

By means of a recycling process, with the steps of grinding and calcination, it is possible to transform the gypsum residue into a recycled binder, thus reducing the consumption of the mineral that originated it.

The gypsum recycling is characterized by the calcination of gypsum waste powder in temperature-controlled ovens. However, this procedure requires more investment and productive techniques, running away from the research scope which proposed to reuse the gypsum in a simpler way.

For the gypsum reuse, it was necessary to make a manual trituration and after that a sieving in order to obtain a powder thinner than 0.42 mm.

Application

For the gypsum residue application in the manufacture of 3D decorative panels, five alternative compositions were proposed to replace the use of the commercial gypsum, or cement, or both simultaneously. A standard sample was also produced to work as a comparison, as shown on Table 2.

Table 2. *Compositions Developed for the Study and Manufacture of the Samples Panels*

Composition	Commercial Gypsum	Reused Gypsum	Cement	Sand	Water
01	0.5	0.5	0.8	0.2	1
02	0	1	0.8	0.2	1
03	1	0.4	0.4	0.2	1
04	1	0.8	0	0.2	1
05	0.7	0.6	0.5	0.2	1
Standard	1	0	0.8	0.2	1

Comparative tests were performed between the proposed compositions and the standard, which is generally used by the production industry, to obtain similar or superior results, so the new compositions can be presented as technically acceptable products by the market.

The water absorption test according to Brazilian standard NBR 9778 (2005) - Hardened mortar and concrete - Determination of water absorption, voids index and specific mass.

The unit mass was determined by taking note of the mass of the panels in an electronic balance with precision of 0.1 g and the volumes in graduated measuring bucket.

Materials

Commercial Gypsum

The commercial gypsum used in this research is classified as coarse gypsum for casting by the Brazilian standard NBR 13207 (1994).

The gypsum acquired took 5 minutes to start the setting time and 15 minute to finish it. The setting time test was performed by following to the Brazilian standard NBR 12128(1991). The used gypsum has a fineness modulus of 2.62. The calculation was made according to the Brazilian standard NBR 12127 (1991).

In Brazil, the gypsum segment is expanding, with an annual growth rate of 8%, and it has even higher growth expectations (SINDUSGESSO, 2007; Pinheiro, 2011). This is mainly due to the dissemination of alternative construction systems, the low cost of gypsum and the high purity content of the national gypsum deposits.

Gypsum is the generic term for a family of simple binders, consisting basically of more or less hydrated and calcium anhydrous sulfates. They are obtained by the calcination of crude gypsum, consisting of calcium sulfate bihydrate usually accompanied by a certain proportion of impurities, such as silica, alumina, iron oxide, calcium and magnesium carbonates.

Reused Gypsum

The gypsum from residue reuse is coarse gypsum for covering, classified by the NBR 13207 (1994) since there are no standards for recycled gypsum.

The beginning and end of setting time were delayed to the conventional gypsum, beginning with 8 hours and finishing with 24 hours. The obtained fineness modulus was 2.98.

Recycled gypsum is defined as gypsum suitable for use obtained by processes of readjustment to the initial state through already used gypsum. The residue recycling of waste in the component processing sector is restricted to the production segment of gypsum plasterboard, which has its own and consolidated recycling system, from the production process, construction and demolition, in which the treated waste is incorporated to the production process in the processing stage.

According to Gypsum Recycling International (2009) the process is widely used in Europe, the United States and Asia. The system consists of collecting the waste and transporting it to the recycling factory, where the material is subjected to the removal of the excess contaminant, crushed and inserted into the processing of the plasterboards. Gypsum Recycling International (2009) estimates that all waste generated by production and application in construction returns to the production process.

Cement

Portland cement is the worldwide designation for the material commonly known in construction as cement. Portland cement is a fine powder with binding properties, which hardens under the action of water. After hardening, even if it is again subjected to the action of water, Portland cement does not decompose any more.

The cement type used was CP II – Z 32, which means Portland cement with pozzolan and its average resistance in 28 days of 32 MPa. This type of cement generates heat at a slower speed than usual and is recommended for use where the cooling capacity is compromised.

Sand

Sand is a group of degraded rock particles, a material of mineral origin finely divided into granules or granites, composed basically of silicon dioxide, 0.063 to 2 mm. Sand is formed at the surface of the Earth by the fragmentation of rocks by erosion, by the action of wind or water. Sometimes, sand can be transformed into sandstone by a process called sedimentation. It is used in civil engineering constructions, landfills, mortars, concretes andalso in glassmaking. The size of its grains has importance in the characteristics of the materials that use it as a component.

Fine sand was used to produce the 3D panels. The sand was sifted for to obtaina particle size less than 0.6 mm.

Results and Discussions

The samples were molded conforming to the proposed compositions. Once they were done, water absorption and unit mass tests were performed for each composition. The demolding times are given in Table 3.

Table3. *Demolding Time for the Compositions*

Composition	Demolding time
Standard	15 minutes
1	3 hours
2	3 hours
3	4 hours
4	1 hour
5	2 hours

The unit mass of the samples was calculated by Equation 1, and the results are listed on Table 4, where it is verified that only the composition 4 presented variation above 10% in its unit mass compared with the standard. The others kept close values.

$$Mu = \frac{Mass}{Volume} \quad (1)$$

Table 4. *Results ofthe Unit Mass Tests*

Comp.	Mass (g)	Volume (L)	Density (g/L)	Variation
Standard	785.30	0.54	1,465.11	0%
1	400.40	0.25	1,601.60	9%
2	436.80	0.29	1,506.21	3%
3	137.50	0.09	1,527.78	4%
4	768.80	0.46	1,671.30	14%
5	461.80	0.29	1,592.41	9%

When the water absorption test was performed, it was noticed that the composition 4 (total replacement of cement by recycled gypsum) is not feasible for production once it does not resist to the contact with water.

Among the other proposed compositions, only composition 3 presented a higher percentage of water absorption than the standard, but the difference between them is slightly greater than 2%. The water absorption indexwas calculated by Equation 2, and the results are shown in the Table 5.

$$AA = \frac{M_{wet} - M_{dry}}{M_{dry}} * 100\% \quad (2)$$

Table 5. *Results of the Water Absorption Tests*

Comp.	Sample	Dry Mass	Wet Mass	Water Absorption (%)	Average (%)
Standard	a	785.3	898.2	14.38%	13.75%
	b	809.8	916.1	13.13%	
1	a	400.4	427.7	6.82%	7.03%
	b	291.4	312.5	7.24%	
2	a	436.8	457.3	4.69%	4.63%
	b	442.4	462.6	4.57%	
3	a	137.5	160.5	16.73%	15.96%
	b	154	177.4	15.19%	
4	a	768.8	-	-	-
	b	893.3	-	-	
5	a	461.8	484.2	4.85%	4.87%
	b	453.9	476.1	4.89%	

To be considered technically feasible, it is recommended that the proposed composition have a result similar or superior to the standard since there is no technical standards for 3D decorative wall covering panels in Brazil.

To obtain a high-quality product, four basic properties are required for decorative covering: aesthetics, watertightness, thermal comfort and acoustic comfort. In this research, the first two properties were approached. As the result of the tests performed and the visual analysis, it was verified the technical feasibility of compositions 1, 2 and 5.

In the economic feasibility analysis of the panels, the costs per cubic meter of mortar and recycled gypsum were estimated according to the National System of Research of Costs and Indices of the Civil Construction - SINAPI, and the costs were from September 2016 (SINAPI, 2016). The data was considered for the production on industrial scale. It was considered a collection distance in a circumference with 5 km of radius and 3 hours of worker to separate, triturate (using a jaw crusher) and sieve 1 cubic meter of recycled gypsum.The cost compositions are presented on the Tables 6 and 7.

Table 6. *Costs witha Jaw Crusher*

CRUSHER RENT		
JAW CRUSHER 6 cv	R$	40,000.00
USEFUL LIFE CONSIDERED	ANOS	25
MONETARY ADJUSTMENT	%/ANO	6.50
INFLATION	%/ANO	6.50
PROFIT	%/ANO	15.00
ANNUAL VALUE	R$	2,086.97
Considering that 1 year has 2112 business days.		
HOUR VALUE	R$	0.99

Table 7. *Cost Composition of the Production of 1 m^3 ofRecycled Gypsum*

RECYCLED GYPSUM (m3)					
72897	MANUAL LOADOFWASTEINA DUMP TRUCK 6 M3	m3	1.00	15.49	15.49
72899	WASTE TRANSPORT WITH DUMP TRUCK 6M3 - PAVED RODOVIA - DMT UP TO 0,5 KM	m3	1.00	4.14	4.14
6111	SOCIAL CHARGES - WORKER	H	3.00	7.75	23.25
COMP	CRUSHER RENT	H	1.00	0.99	0.99
	SUBTOTAL				43.87
	TOTAL (BDI 25%)				**54.84**

Analyzing the Table 8, it is possible to verify the cost per cubic meter of the proposed compositions. It can be noticed that all of them had an economy in relation to the standard, reaching economy values up to 38%, excluding compositions 3 and 4.

In the Table 8, it is also possible to verify the CO_2 emission reduction per cubic meter of produced mortar, varying from 250 to 1,050 kg of reduction in the compositions viable for production. For each ton of recycled gypsum, 200 kg of CO_2 emissions is saved. For each ton of cement replaced, about the same amount of CO_2 is no longer emitted.

Table 8. *Analysis of Financial and Environmental Feasibility of the Compositions*

Composition	Value	Economy	CO_2 Emission Reduction
1	1,358.25	19.31%	250 kg
2	1,033.25	38.62%	500 kg
3	1,283.25	23.76%	1,200 kg
4	883.25	47.53%	2,400 kg
5	1,188.25	29.41%	1,050 kg
Standard	1,683.25	0.00%	0 kg

Conclusions

Considering the technical and economic analysis, it is proposed to the industry of production of decorative wall covering panels with 3D effects three compositions with insertion of recycled gypsum, reducing the commercial gypsum and/or cement consumption.

The produced 3D panels had a small gain of density, not exceeding 10%, and they increased watertightness, absorbing less water. The alternative compositions presented reduced costs, reaching 38% cheaper than conventional cost, and they can reduce around 1,050 kg of CO_2 emission.

The produced 3D gypsum panels meet the sustainability tripod: environmental, economic and social viability. They provide a reduction of improperly disposed waste and less environmental contamination, in addition to preserving raw material deposit. The panels present a cost reduction, making them accessible and their commercializing viable. In social terms, the recycled gypsum panels can be produced in a work involving selective collection through associations and cooperatives.

References

ABRECON. Sectoral Research Report 2014/2015: *The Recycling of Construction and Demolition Residue in Brazil*. São Paulo, 2015.

Associação Brasileira de Normas Técnicas. NBR 12127: *Gypsum for construction - Determination of the physical properties of the powder*. Rio de Janeiro, 1991.

Associação Brasileira de Normas Técnicas. NBR 12128: *Gypsum for civil construction.* Rio de Janeiro, 1994.

Associação Brasileira de Normas Técnicas. NBR 10004: *Solid Waste - Classification.* Rio de Janeiro, 2004.

Associação Brasileira de Normas Técnicas. NBR 9778: *Mortar and hardened concrete - Determination of water absorption by immersion - voids index and specific mass.*Rio de Janeiro, 2005.

Athas, Fernanda. *3D wall covering is trend in " Fashion Week of Architecture " in SP*. Folha de S. Paulo, São Paulo, 06 Mar. 2016. Available in: http://bit.ly/2CUT WkN. [Accessed 23 Sep. 2016].

Bauer, L. A. Falcão. *Construction Materials*. Vol 1. 5thed. Livros Técnicos e Científicos Ed., Rio de Janeiro, 2000, p. 471.

Brasil. Ministério do Meio Ambiente. Agenda 21:*Sustainable Construction.*Available in: http://bit.ly/2CS9pBV. [Accessed 14 Dec. 2016].

Brasil. Ministério do Meio Ambiente. Conselho Nacional do Meio Ambiente. *Resolution n. 307, 5 Jul. 2002*. It establishes guidelines, requirements and procedures for the management of construction residue.Brasília, DF: Diário Oficial da União, 17 Jul. 2002. Available in: http://bit.ly/X2jhUM. [Accessed 14 Dec. 2016].

Brasil. Ministério do Meio Ambiente. Conselho Nacional do Meio Ambiente. *Resolution n.431*, 24 May 2011. *It changes the art. 3rd of the Resolution 307, 5 Jul. 2002*, ConselhoNacional do MeioAmbiente – Conama, establishing new classification for gypsum.Brasília, DF: Diário Oficial da União, 25 may 2011. Available in: http://bit.ly/2CU70XC. [Accessed 14 Dec. 2016].

Construindo Decor. *3D Gypsum.* Available in: http://bit.ly/2DoI9fw. [Accessed12 Dec. 2016].

Gypsum Recycling International.Brochure Gypsum Recycling International. Available in: http://bit.ly/2D708dG.[Accessed 20 Dec. 2016].

Melo, D. de C. Pessoa. *Process of Gypsum / Residue Calcination in a Continuous Rotary Kiln for the Production of Beta Recyclable Gypsum*. Tese de Doutorado, Programa de Pós-Graduação em Engenharia Química da Universidade Federal de Pernambuco,UFPE, Recife-PE, 2012.

Nagalli, André. *Construction Solid Residue Management.*São Paulo: Redação de Textos, 2014.

Pinheiro, S. M. de Moraes. *Recycled Gypsum: Evaluation of Properties for Use in Components*.(Theses) Tese de Doutorado, Programa Pós-Graduação da Faculdade de Engenharia Civil da Universidade Estadual de Campinas – UNICAMP, Campinas-SP, 2011.

SINAPI.*National System of Research of Costs and Indices of the Civil Construction.* Caixa Econômica Federal. Reference of September 2016.

SINDUSGESSO - SINDICATO DA INDÚSTRIA DO GESSO DO ESTADO DE PERNAMBUCO. *Consumption of Gypsum in Brazil*.Press Office. Brazil, 2007.

Zanta, V. M.; Cartaxo, G. A. A.; Freitas, I. M. D. P. De. *Analysis of the Gypsum Residue Management in the city of Salvador-BA.*In: XXXIII ENCONTRO NACIONAL DE ENGENHARIA DE PRODUÇÃO. Salvador-BA, 2013. Availablein: http://bit.ly/2DrawK8. [Accessed 12 Dec. 2016].