Revista Brasileira de Ciências Ambientais
Brazilian Journal of Environmental Sciences

Electrical installations running through masonry walls: developing waste generation indicators for environmental performance analysis

Embutimento de instalações elétricas em alvenarias: desenvolvimento de indicadores de geração de resíduos para análise de desempenho ambiental

Luna Ollin Steffen[1], Charles Jaster de Oliveira[2], Annelise Nairne Schamne[1], André Nagalli[1]

ABSTRACT

Waste generation is one of the most relevant environmental aspects of the construction industry. About 47 million tons of construction and demolition waste are collected annually by Brazilian municipalities. One of the activities that generates waste is cutting chases on walls for installations. However, there are no waste generation indicators for this activity. Understanding waste generation processes enables managers to prevent them and promote their proper environmental management. This study assessed the generation of waste resulting from the cutting of clay bricks for electrical installations using three tools: milling cutter, marble saw, and cold chisel. The study included data collected from residential construction works and experimental data collected from the construction of real-scale walls. In a laboratory, five different wall configurations were built and the three tools mentioned were used to cut a chase on the walls. The results were statistically analyzed to define a waste generation index (WGI) by linear regression. The type of tool employed had no influence on the waste generation index, which was 26.5 ± 2.6 kg/m^2. However, the tools used directly influenced the quality of the service, productivity, and the volume of waste generated. The waste from the milling cutter showed the smallest maximum aggregate size and the largest bulk density, followed by the waste resulting from the marble saw and the cold chisel. The marble saw and cold chisel waste samples had around 78% of their composition in the coarse aggregate grain size range. The milling cutter waste samples were the finest and had on average 60% of their composition in the fine aggregate grain size range. The width of the chases made with the milling cutter were smaller and more consistent than those made with the cold chisel,

RESUMO

A geração de resíduos é um dos aspectos ambientais mais relevantes da indústria da construção. São coletados anualmente pelos municípios brasileiros 47 milhões de toneladas de resíduos de construção e demolição. Uma das atividades que ocasiona a geração de resíduos é o corte de paredes para o embutimento de instalações. Contudo, não se dispõe de indicadores de geração de resíduos para essa atividade. Compreender os processos geradores de resíduos possibilita aos gestores atuar de modo a preveni-los e a promover uma gestão ambiental adequada. Neste estudo foi avaliada a geração de resíduos resultante do processo de corte de alvenaria cerâmica para embutimento de instalações elétricas por meio de três ferramentas de corte: talhadeira, serra mármore e fresa. O estudo consistiu na coleta de dados em obras de edifícios residenciais e em experimentos em ambiente laboratorial em escala real. Em laboratório, cinco diferentes configurações de muros e as três citadas ferramentas de corte foram ensaiadas. Os resultados foram analisados estatisticamente e foi possível definir uma taxa de geração de resíduos por meio de regressão linear. Os resultados mostraram que o tipo de ferramenta não influenciou a taxa de geração de resíduos, que ficou em 26,5 ± 2,6 kg/m^2. Entretanto, as ferramentas influenciaram diretamente a qualidade e a produtividade do serviço e o volume total de resíduo gerado. O resíduo oriundo da ferramenta fresa apresentou a menor dimensão máxima característica e a maior massa unitária, seguido dos resíduos resultantes do corte da serra mármore e da talhadeira. Os resíduos destas tiveram 78% de sua composição na faixa granulométrica de agregados graúdos. Já o proveniente da cortadora de parede do tipo fresa foi o mais fino e apresentou em média 60% de sua composição na faixa granulométrica de agregados miúdos. A largura dos cortes feitos com a fresa foi menor e mais consistente que a dos feitos com talhadeira, que apresentaram

[1]Universidade Tecnológica Federal do Paraná – Curitiba (PR), Brazil.
[2]Universidade Positivo – Curitiba (PR), Brazil.
Correspondence address: André Nagalli – Rua Deputado Heitor de Alencar Furtado, 5.000 – Cidade Industrial – CEP: 81280-340 – Curitiba (PR), Brazil.
E-mail: nagalli@utfpr.edu.br

Conflicts of interest: the authors declare no conflicts of interest.
Funding: none.
Received on: 10/06/2021. Accepted on: 04/25/2022.
https://doi.org/10.5327/Z217694781240

which showed irregularities and larger dimensions than necessary. From the waste generation indicators obtained in this study, construction managers will be able to choose more appropriate cutting tools and improve their planning and management systems to minimize associated environmental impacts.

Keywords: construction and demolition waste; waste generation index; sustainable construction

irregularidades e dimensões maiores que as necessárias. Com base nos indicadores de geração de resíduos obtidos neste estudo, é possível que gestores de construções escolhem apropriadamente as ferramentas de corte utilizadas e aprimorem seus sistemas de planejamento e gestão, visando à minimização dos impactos ambientais associados.

Palavras-chave: resíduos de construção civil; taxa de geração de resíduos; construções sustentáveis.

Introduction

The environment, over the years, has been subjected to strong negative impacts caused by economic policies that have promoted uncontrolled urbanization and excessive exploitation of natural resources (Duarte et al., 2021). The environmental problems associated with the construction industry, in addition to using a large amount of natural resources, range from the incorrect segregation of waste to construction materials being used inefficiently (Scalone et al., 2016). In Brazil, the disposal of construction and demolition waste (CDW) quite often occurs in inadequate places, resulting in social, economic, and environmental problems (Biju et al., 2021).

Around 80% of the CDW is composed of inert materials such as concrete, ceramics, tiles, and bricks which have high recycling potential (Tavira et al., 2018). However, from a technological, environmental, and management perspective, CDW recycling faces complicated issues that require resolution (Galán et al., 2019). One option to alleviate the negative impacts would be to recycle construction and demolition waste as recycled aggregate in the manufacture of non-structural concrete (Juan-Valdés et al., 2018). CDW recycling has been commonly advised in line with the principle of circular economy (Ghisellini et al., 2018).

The European Union construction industry generates around 900 million tons per year of waste, which represents 30% of all waste produced (Martínez et al., 2016). In Brazil, this percentage is higher than 50% and the amount of CDW generated is more than 100 million tons per year. Also, the recycling rate is still very low (below 10%) (ABRECON, 2020).

Many countries have developed regulations to minimize CDW. Implementing these regulations requires an understanding of the magnitude and material composition of the waste stream (Li et al., 2013).

Understanding factors that influence the generation of construction waste is complex (Nagalli and Carvalho, 2018). The main obstacle in researching and studying about CDW management is the absence and/or inaccuracy of data related to quantities, cost, and environmental impact (Abdelhamid, 2014).

Many methods have been used by researchers to measure or predict waste generation levels. Some examples include comparing contractor records (Skoyles, 1976), separating and weighing waste at the construction site (Bossink and Brouwers, 1996), using cargo records from waste transport trucks (Poon et al., 2001), making direct observations (Formoso et al., 2002), analyzing material flow (Cochran and Townsend, 2010; Li et al., 2013), and using the waste weight/volume method compared to the built area (Yost and Halstead, 1996; Fatta et al. 2003; Shi and Xu, 2006; Bakshan et al., 2015).

These studies can be divided into two categories: studies that determine an overall CDW generation amount in a region and those that measure the CDW generation index at project sites. In the second category, it is possible to establish a waste generation index (WGI) for each type of waste, considering all stages and construction processes in a project (Li et al., 2013).

The construction waste generation index is a useful tool for estimating the amount of construction waste and can be used as a benchmark to enhance the sustainable performance of the construction industry. This index is a meaningful tool to promote construction waste management and to help project stakeholders gain more insight into waste management performance and review current construction practices (Li et al., 2013). Also, the development of accurate tools to estimate waste generation contributes to Building Information Modelling (BIM), with designing out waste, better control of materials, cost analysis, planning of activities, and waste management along the life cycle of the building (Ajayi et al., 2015; Akinade et al., 2018).

However, it is difficult to accurately quantify the waste produced in construction activities. The amount of waste from each project can vary, for example, according to the construction process, the experience and size of the team, the supervision efficiency of the management team, the work schedule, and the commitment of company managers to environmental issues and waste management (Wu et al., 2014; Nagalli and Carvalho, 2018).

In Brazil, most of the electrical and hydraulic installations run through the walls and produce masonry waste resulting from cutting chases on the walls. Such waste is generated in a dispersed manner on the construction site. Studies around the world show that masonry waste is one of the most generated CDW, ranging from 3.4 to 58.6 kg/m^2 (according to the gross floor area) (Seo and Hwang, 1999; Li et al., 2013; Mália et al., 2013; Bakshan et al., 2015). Due to the large volume of ceramic waste generated, its reuse should prioritize solutions with low technologies and low investment costs. Rational dosing and quality control procedures must be pursued, seeking to minimize losses so that they have little interference in construction activities and make it possible to reach the final quality specifications foreseen for the building (Miranda et al., 2009).

Although other techniques that do not cut masonry walls are technically possible and prevent waste generation, these are not usual in developing countries due to high costs and the construction culture. Thus, understanding the waste generated from cutting masonry walls is important, aiming at reusing or recycling this material. Different techniques and equipment are used to chase walls for installations. Some save time; others generate more or less waste. Exploring this type of activity and estimating a WGI for the masonry waste can help builders invest in more qualified techniques and equipment, resulting in less time and resources, decreasing waste generation, or increasing their recycling potential.

Considering that masonry is a usual construction process in Brazil, this study aimed to critically evaluate the generation of waste from the activity of cutting chases on ceramic blocks to run electrical installations and propose a WGI for the construction waste generated by this activity. Construction site situations were evaluated, and experiments were carried out that allowed quantifying and characterizing such waste.

An electrical installation basically involves cutting a chase on a masonry wall made of ceramic hollow blocks. This activity can be performed manually, through a slitter, or using equipment (milling machine or saw) for greater productivity. The chase usually reaches the first vertical septum of the block, providing sufficient room for the conduit. Nevertheless, some tools make cuts that are rougher than others; therefore, generating more waste. For this reason, a WGI should be estimated in terms of the amount of waste per unit of cut surface area.

This research aimed at analyzing the environmental impacts of cutting chases on masonry walls to run electrical installations and at estimating waste generation indicators. The waste generated from the cutting of clay bricks using three tools was evaluated: milling cutter, marble saw, and cold chisel.

The estimation of construction waste in electrical installations will help evaluate the tools used to cut the walls and consequently promote better waste management, effective construction site management, and opportunities to improve the activity using the appropriate equipment and generating less waste.

Literature review

Material loss is the main cause of waste generation. It can occur because of inadequate solutions, during material procurement, during transportation, upon material receipt, when storing at the construction site, during work execution with increased consumption of materials to correct imperfections and project failures, or as a result of the person performing the work. Waste is also generated after the building is occupied when materials are wasted due to repairs (Fraga, 2006).

Accurately quantifying waste has always been a challenge and a relevant topic to be investigated because accurately estimating the amount, type, and time of CDW generation is essential for planning and managing waste and applying the 3R's of sustainability (Reduce, Reuse, and Recycle).

To contextualize the topic of study, a literature review from 2010 to 2020 was carried out in the Scopus database to verify the main publications about construction waste generation over the years. The combination of search terms was: "construction" AND "waste generation" OR "recycling of ceramic waste" OR "optimization of waste generation" OR "construction and demolition waste" OR "waste generation index".

The criteria to select the papers were that search terms should appear in the title, in the abstract, or as a keyword; publications should be available in Portuguese or English; and papers should have been published in Journals or Conference Proceedings with open access.

The search revealed 652 documents that met the criteria. The number of publications has grown since 2014 (Figure 1). Most publications are from Spain and China, followed by the United Kingdom and Brazil (Figure 2).

Studies have tried to improve the quantification of waste from construction activities to promote effective waste management (Lu et al., 2011; Wu et al., 2014). Case studies, literature reviews, and observations of construction works are the common methods applied to introduce the research before the development of tools, methods of estimation, or practices that help quantify construction and demolition waste.

Most studies focus on analyzing the sources of waste during construction activities and classifying the types of waste that are most generated before suggesting any solution. Exploring by activity, process, and phase of construction allows for identifying critical points or barriers during the construction that can impact the performance of the construction activities and waste management. This type of analysis helps understand the impacts of the activities and identify actions that can be implemented as early as in the design phase to avoid low performance, delays in the project, high costs in the project, loss of materials, or waste generation.

However, more than developing efficiency tools to estimate construction waste, prevention as early as the design of the architectural project should be considered, with practices of non-generation of waste, such as the correct choice of the material to be used and the construction system to be adopted. Improving the project's details reduces losses due to an inaccurate framework, like material procurement, when done without planning.

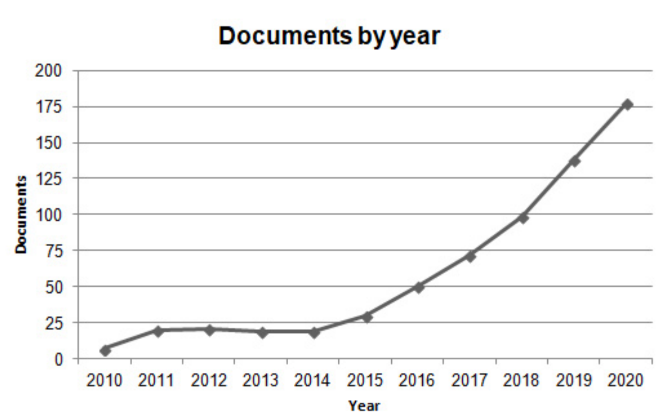

Figure 1 – Publications by year, considering the period from 2010 to 2020.

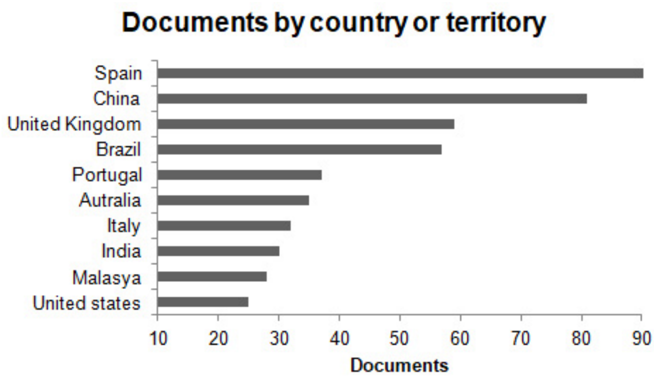

Figure 2 – Publications by country or territory in the period from 2010 to 2020.

The quantification, measurement, and prediction of waste in waste management have received the attention of researchers over the years (Adjei, 2016). These actions have become crucial tools for decision-making in the environmental and economic dimensions, and such decisions become progressively based on well-founded quantitative data for each activity in construction (Jalali, 2007).

Materials and methods

This research is classified as applied, exploratory research, with field and laboratory investigations. In the first part of this research, six worksites located in the city of Curitiba, Paraná, Brazil, were analyzed. As common characteristics, the chosen work sites had walls made of ceramic blocks, conduits for the passage of wiring, and the construction of multiple residential floors. During the fieldwork, data and information were collected about the type of equipment used to cut masonry; the diameter of the conduits used; the masonry characteristics (block type, block position, wall cladding situation, and average thickness of the laying joints), and the characteristics of the chases (width and length).

In the second part of the research, an interview was conducted with employees that performed the activity to verify their experience, level of training, and education regarding waste management.

To analyze all six work sites, a bucket of 15 L, a measuring tape, and a portable scale (WH/A07 brand, 50 kg capacity) were used for field measurements. With the help of a broom, mason spoon, and shovel, samples from the chases cut on the walls were collected. The bucket was used to weigh the samples and calculate the unitary mass.

The samples were coded as follows (Equation 1):

$$LxTy \quad (1)$$

Where:
L = the place where the analysis was made (C = construction site, W = wall in lab);
x = a number that identifies the work;
T = the type of the tool used to cut the masonry (M = milling cutter, S = marble saw, or C = cold chisel);
y = a number that identifies the sample.

A milling cutter is designed to open straight and curved cuts on walls of solid or hollow bricks, cement blocks, or plastered walls. It has a toothed disc and opens a tear on the wall after the machine is used, without using any other equipment. A marble saw is used for straight and curved cuts in all types of ornamental stone, brick, tiles, floors, ceramics, concrete blocks, etc. Each material to be cut requires a cutting disc with appropriate specifications. Finally, a chisel is a cutting tool made of a steel body, circular, rectangular, hexagonal, or octagonal in section, with one end flat and sharp, and the other beveled called a head. It can be used after the chase has been delimited by saw marble or it can be used alone, with the help of a hammer.

The WGI proposed in this work will be calculated in kg/m^2 (mass of the chase waste/chase area) and can be easily linearized for different width measurements. For electrical installations (conduits and lightboxes) to run through the wall, the depth of the external wall chase until the end of the first hole of the ceramic blocks was considered. As a result, the WGI, the time required to perform the chase, the unit mass of the material, and the granulometry are conditioned to the chase being made until the end of the first hole.

In the laboratory, walls were built (Figure 3) with different block configurations (dimensions and position) to simulate the work environment. The W5 wall (each wall was named W with a sequential number from 1 to 5) was built in the stretcher configuration to simulate thicker walls with a greater plaster area (common on external walls). The chases were cut by a professional worker using the following equipment: a BRIC 35 milling cutter, a conventional marble saw, and a cold chisel. Four types of ceramic blocks were used, more common in the local market, with the following sizes: 9 × 14 × 19 cm (308 blocks), 9 × 19 × 29 cm (54 blocks), 11,5 × 14 × 24 cm (88 blocks), and 14 × 19 × 29 cm (54 blocks).

The wall design sought the best fitting of the blocks for overall stability and the height of the wall was limited so that the electrician would not need to use scaffolding or stairs. The walls were built according to the Brazilian technical standards, with a vertical and horizontal settlement joint of 10 mm. The chase values were standardized as 3.5 cm to adjust to the diameter of the milling equipment. The length of 1.25 m was defined as standard.

Three chases were cut per wall and per type of tool, thus each type of block was left with 9 chases, 3 made with a milling cutter, 3 with a marble saw, and 3 with a chisel, totaling 45 chases for data collection.

The samples were weighed in the laboratory with a Digimed kn5000 model scale, with 0.1 g to up to 5 kg precision. After weighing, the last sample of each wall per tool was chosen (W1M3, W1S3, W1C3,

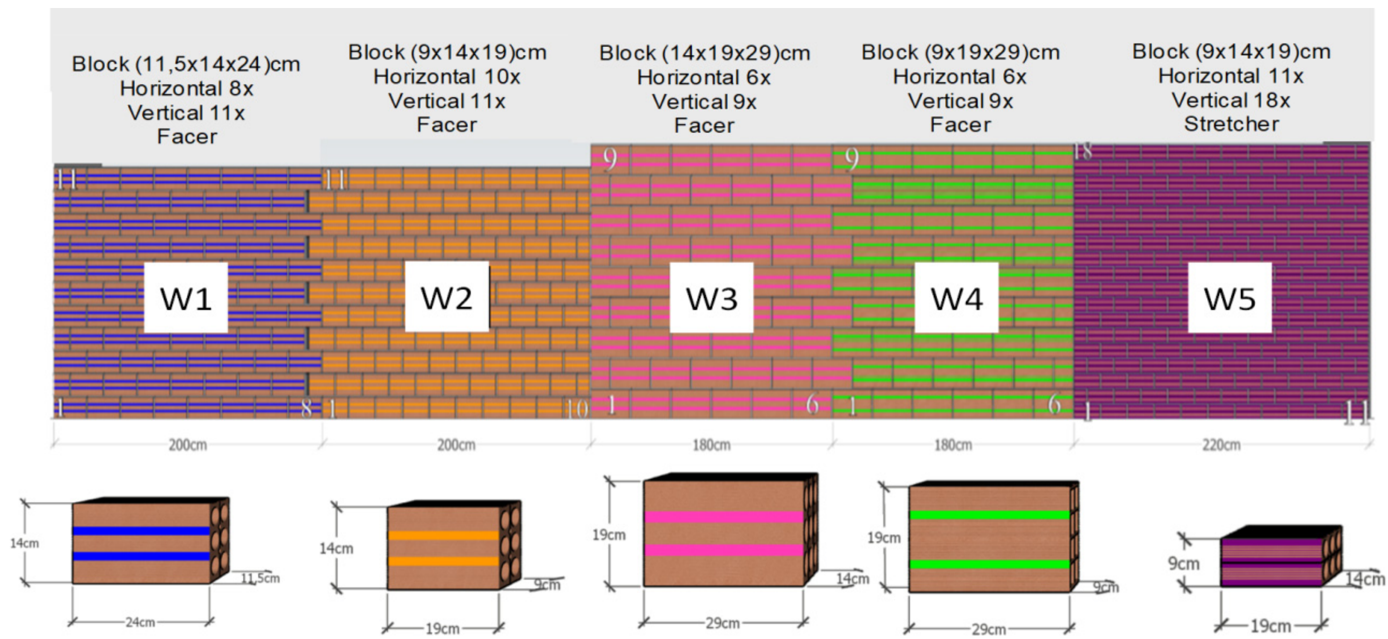

Figure 3 – Schematic layout of the walls built in the laboratory.

W2M3...), totaling 15 samples, five for each tool, for the granulometry assay according to the Brazilian standard (ABNT, 1987). For the unit mass test, using NBR 7251 standard as a basis (ABNT, 1982), the samples of the same tool per wall were mixed (W1M1, W1M2, W1M3...), thus obtaining 5 waste samples per tool. The waste was placed in a container of known weight and volume for the subsequent calculation of the unit mass. The assay was done in triplicate.

To analyze the quality of the data obtained and the relationship between them to obtain the WGI, the results were analyzed and treated with IBM software SPSS statistics 20, using the statistical tests Shapiro-Wilk and Bonferroni. Finally, linear multiple regressions were applied to obtain the WGI. The predictor variables (the types of tool and block) are related to the variable of interest (waste generation index); however, the degree of relationship is unknown.

Since the normal distribution is a requirement for the application of linear regression, datasets were evaluated using a bar and a scatter chart, box diagram (boxplot), parametric analyses, and Shapiro-Wilk statistical test to verify the normality of the data that make up the dependent variable.

ANOVA parametric analysis (Analysis of variance) — which is indicated for three or more data groups — was used to identify the correlation between groups of independent variables. The Bonferroni test was then conducted to identify the significant differences between the groups (Mundstock et al., 2006). The independent variables that influenced the dependent variable were used in linear regression analysis. The significance level used was 0.05, with a 95% confidence interval (Ferreira and Patino, 2015).

Results

Construction diagnosis

The results of the study conducted on the six housing works visited showed that to cut chases on masonry walls: 48% of the works used a marble saw in conjunction with a chisel; 38% used a chisel, and 14% used a milling cutter.

As for the profile of the worker, the activity of masonry cutting was performed by electricians, with experience ranging from 4 to 30 years of work. However, none of them reported having the training to cut the chases or to correctly handle the tools.

During field inspections, the chases were observed to have been cut to sizes above the desirable, compared to the size of the electrode to be installed. All works used blocks in rowlock position and conduits of 3/4". The size of the chases where electrical conduits would run through varied from an average of 28 mm to 160 mm wide. The vertical and horizontal laying joints showed a great difference between the works, ranging from a dry joint (0.0 cm) to 2.7 cm.

Table 1 shows that the highest WGI was obtained with the chisel in work 6, with 29.73 kg/m^2, followed by work 4, with 29.35 kg/m^2, in which the highest values of vertical and horizontal joints are found. The lowest WGI was found in work 5, with 26.78 kg/m^2, in which one of the settlement joints of the block was zero. The joints did not show significant interference in the WGI results because the density of the mortar and the density of the ceramic block material is similar. In all, more than 56 meters of masonry chases were analyzed, totaling 97.87 kg of heavy waste in the pilot study.

Table 1 – Summary of the results analyzed in the pilot study.

Construction Site	Block Dimension (cm)	Vertical Joint (cm)	Horizontal Joint (cm)	Total Length (m)	Total Mass (kg)	WGI (kg/m²)
C1M	11.5 × 19 × 24	1.7	2.7	12.80	13.98	27.20 (2.08)
C2S	11.5 × 14 × 19	0.7	2.0	19.41	34.39	27.28 (2.21)
C3S	9 × 14 × 19	1.7	2.0	4.61	5.24	27.60 (1.20)
C4S	9 × 14 × 19	2.0	2.5	3.99	5.80	29.35 (2.18)
C5M	14 × 19 × 29	0.0	1.5	9.53	20.63	26.78 (2.56)
C6C	14 × 19 × 29	1.0	1.0	6.03	17.84	29.73 (3.01)

The results for bulk density were: 1,100.7 kg/m^3 (C1M), 1,080.1 kg/m^3 (C5M), 1,021.8 kg/m^3 (C3S), 993.6 kg/m^3 (C2S), and 908.4 kg/m^3 (C6C). It was not possible to measure the bulk density of the C4S sample because the amount of material collected is lower than the measuring container. It should be noted that the highest densities were obtained for the milling tool, which is consistent with the type of waste observed (with lower granulometry). The difference between the lowest (908.4 kg/m^3) and the highest (1,100.7 kg/m^3) measures is considered significant (17.5%) for waste management practices (collection structure, predictive calculations, BIM).

When assessing the activity performed by the electrician, the milling cutter is observed to be the most effective equipment because it is faster and accurate, in addition to having widths with more constant measurements. However, the diameter of the chase is limited to the size of the cutting discs available on the market. The dust generated during machine use goes downwards, so the level of dust produced is low compared to the marble saw.

Although the use of the marble saw results in a precise cut, the procedure, in addition to producing more dust than the other two cutting tools analyzed, is considerably slower than the milling cutter because the worker has to cut the masonry wall twice and then use the chisel to remove any residues between the two cuts.

Using a chisel and a hammer only, without delimiting the chase with a marble saw, makes the work even slower, less precise, and less ergonomic, in addition to producing chases that are larger than expected. However, it has no considerable generation of dust compared to the marble saw and the milling cutter.

Results of the experimental investigation

The first stage of experimental work consisted of verifying the conformity of ceramic blocks regarding their dimensions. The values were compared with Brazilian standards and all blocks were within the limits of deviation.

Once the walls had been built, the time required to cut the chases was measured. The mean time variable was directly dependent on the type of tool used. The time required to cut a one-meter chase on a masonry wall with the milling cutter (19 s) was six times shorter than that using the marble saw (1 min 54 s) and approximately 14 times shorter than that using the chisel (4 min 15 s). It is also observed that the sum of all times of execution of the chases made with the milling cutter is very close to the execution time of one work only made with the chisel.

The WGI was calculated based on the waste generated when cutting the three chases on each of the five walls. The average WGI and the respective standard deviation were 24.85 (2.84) kg/m² for the milling cutter, 23.45 (3.01) kg/m² for the marble saw, and 26.38 (4.68) kg/m² for the chisel. It is important to highlight that the area used in the calculation is the area of the chase surface, not the gross floor area (GFA), as usual.

The data obtained on the construction sites were collected without controlling the widths or the type of block used to build the wall, unlike the laboratory study, in which all samples of each tool went through the same process and had the proposed width of 3.5 cm.

The analysis of the widths of the chases cut showed that the performance of the chisel is lower than that of the other tools. The average widths of the chases cut with a chisel (4.6 cm) did not follow the default value of 3.5 cm that had been proposed. However, lengths were controlled for all samples. On the other hand, with the marble saw and the milling machine, it was possible to meet the desired chase width (3.5 cm). Figure 4 shows the difference in the widths and finish of the edges between the tools used on Wall W1.

Concerning bulk density, the waste generated by the milling cutter had average results of 1,134 (31.8) kg/m^3, marble saw 1,054.5 (31) kg/m^3, and chisel 1,017.1 (33.7) kg/m^3. Note that the results are compatible with measurements performed on the construction sites. Only the results obtained with a chisel are slightly higher, which is attributed to the quality of sample collection in the laboratory (controlled environment).

The results obtained for density are also compatible with those observed in the literature. De Brito et al. (2005) and Tanaka et al. (2010) measured bulk density from red ceramic recycled aggregates and obtained results of 1,160 and 1,260.0 kg/m^3, respectively. Lovato et al. (2012) and Frotté et al. (2017) obtained a bulk density of 1,425.0 and 1,390 kg/m^3, respectively, for recycled fine aggregates. Liu et al. (2011) and Lovato et al. (2012) obtained a bulk density of 1,165 and 1,067.0 kg/m^3, respectively, for recycled coarse aggregates.

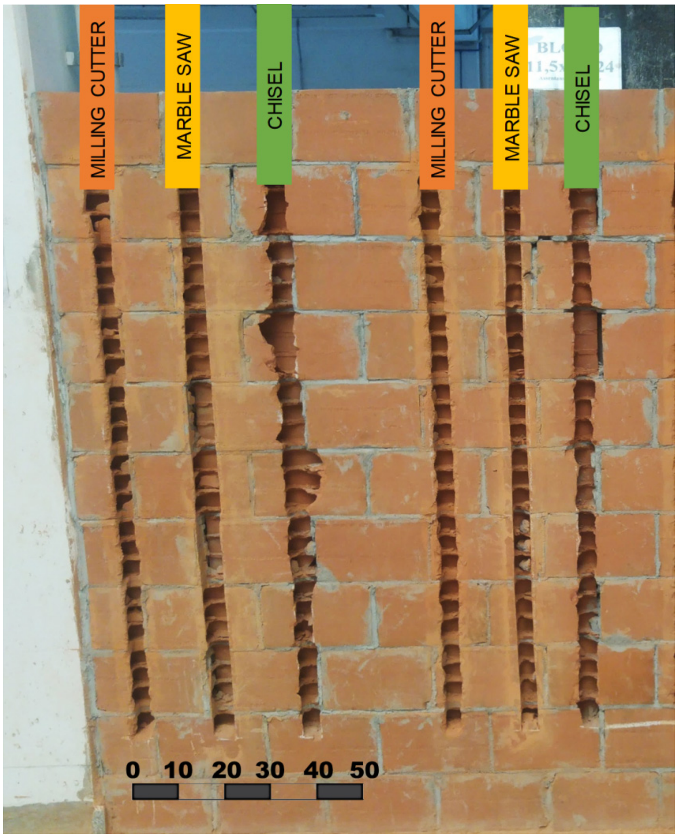

Figure 4 – Comparison of widths and chase finish for different tools on Wall 1 (centimetric scale).

From the granulometric analysis performed (Figure 5), it is possible to conclude that milling cutter samples have a maximum characteristic dimension (MCD) from 9.5 to 19 mm, while for the marble saw and chisel samples, MCD is between 38 and 76 mm. The finite module, which represents the sum of the accumulated percentages in aggregate mass, with sieves in the regular size range, divided by 100, demonstrates that the waste is thicker for the marble saw and the chisel.

From the analysis of granulometric curves (Figure 5), it was also found that the milling cutter waste has a higher concentration in the groups of fine aggregate (< 4.8 mm). The granulometric curves of the marble saw and the chisel are very similar and concentrate the percentage of waste in the larger granulometric range. However, the marble saw samples are more similar to each other when compared to the chisel samples.

It was found that 59.9% of the composition of the milling cutter samples are in the small granulometric range and 20.5% in the large, while 81.4% of the composition of the marble saw samples are coarse aggregates and 13.07% are fine aggregates. For the chisel, 75.3% are coarse aggregates, and 20.8% fine aggregates. It is concluded that the tool used to cut chases on masonry walls influences the bulk density of the material due to the granulometric distribution observed.

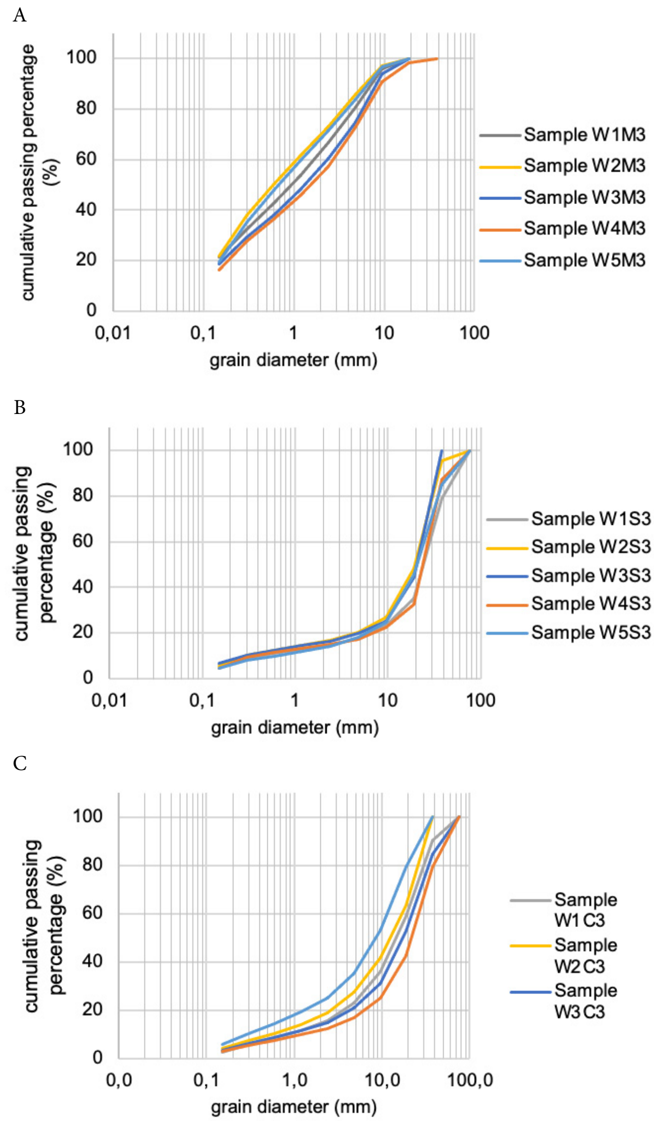

Figure 5 – Results of the particle size analysis performed for the three tools: (A) milling cutter; (B) marble saw; (C) chisel.

Even though the masonry waste studied includes a wide granulometric range, scientific works have confirmed that it can be used as a recycled aggregate for the manufacture of mortars and concretes, either sifted or not (Khalaf and Devenny, 2004; Corinaldesi and Moriconi, 2009; Behera et al., 2014; Frotté et al., 2017; Gayarre et al., 2017; Evangelista et al., 2018; Shahidan et al., 2017).

Statistical analysis

The Statistical Shapiro-Wilk test on the dependent variable (WGI) was applied to the results of the experimental and field investigations. IBM-SPSS® statistical software was used for normality verification. The dependent variable (WGI) was analyzed with two independent variables: block type and tool used. Then, the tool groups and wall/block groups were verified separately as to the generation index (dependent variable), already excluding the spurious data. The variance test (ANOVA) was used, which is indicated for three or more data groups.

For the field investigation (construction sites), the p-values found are above 0.05, thus the hypothesis of normality for the dependent variable is not rejected in any case. No outlier data were witnessed. The results are shown in Tables 2 to 5.

For the laboratory (experimental) investigation, the p-value values are above 0.05, so the hypothesis of normality for the generation index is not rejected in any case.

However, unlike data from the field investigation, in the boxplot graph (Figure 6) that analyzes the empirical distribution of laboratory data, the statistical analysis identified two outliers, samples W1C2 and W3S3.

Table 2 – Variance test - WGI vs block (field investigation).

	Block type	Shapiro-Wilk		
		Statistics	Sample No.	p-value
WGI (kg/m²)	11.5 × 19 × 24	0.960	4	**0.778**
	11.5 × 14 × 19	0.900	5	**0.408**
	9 × 14 × 19	0.942	5	**0.679**
	14 × 19 × 29	0.945	7	**0.686**

Table 3 – Variance test - WGI vs tool (field investigation).

	Tool	Shapiro-Wilk		
		Statistics	Sample No.	p-value
WGI (kg/m²)	Milling cutter	0.900	8	**0.289**
	Marble Saw	0.977	10	**0.949**
	Cold Chisel	0.790	3	**0.092**

Table 4 – Variance test: WGI vs block (experimental investigation).

	Wall	Shapiro-Wilk			
		Block type	Statistics	Sample No.	p-value
WGI (kg/m²)	1	11.5 × 14 × 24	0.858	9	**0.092**
	2	9 × 14 × 19	0.954	9	**0.733**
	3	14 × 19 × 29	0.850	9	**0.075**
	4	9 × 19 × 29	0.981	9	**0.971**
	5	9 × 14 × 19	0.901	9	**0.255**

Table 5 – Variance test: WGI vs tool (experimental investigation).

	Tool	Shapiro-Wilk		
		Statistics	Sample No.	p-value
WGI (kg/m²)	Milling cutter	0.928	15	**0.256**
	Marble Saw	0.963	15	**0.738**
	Cold Chisel	0.940	15	**0.382**

The W1C2 sample resulted in the highest WGI and the W3S3 sample in the lowest WGI.

After analyzing the videos of the chase cutting process in an attempt to understand what caused the outliers, a considerably large piece of mortar on Wall 1 came loose from the wall after the electrician scraped the wall with a butcher, already at the end of the chase cutting. For the Wall 3 sample, there was no irregularity when analyzing the videos.

For both situations (field and laboratory investigations), the ANOVA test resulted in a p-value greater than 0.05, which means that the WGI is not significantly different between the tool groups.

Considering the types of blocks, the data obtained in the pilot study have a strong relationship between them and do not show significant WGI differences if the groups of tools used are considered, or the type of block analyzed. It was found that for the construction site samples, there is no significant WGI difference between the "block type" groups since the p-value resulted in a number greater than 0.05.

As for the results obtained in the laboratory, considering that the p-value was equal to zero, this demonstrates that the block groups (walls) differ from each other concerning the WGI. To find which pairs of groups differ from each other, it was necessary to do a statistical post-test (Bonferroni test).

From the Bonferroni test, it was observed that the results obtained in the laboratory for wall number 3 are not statistically related to the others. Thus, when proposing the WGI in this study, we chose to disregard the values found for Wall W3, built with blocks of 14 × 19 × 24 cm. The proposed WGI, which correlates the average results obtained in the field and laboratory investigations, does not consider the results obtained for Wall W3.

It is concluded that the type of ceramic block used may influence WGI in some cases. However, this influence is small (considering the groups of blocks analyzed), since in the only groups that showed significant difference among themselves, the p-value was 0.05. The burning process, the density of the clay mass, and the amount of mortar between layers, all these factors, in the outlier points, can influence the

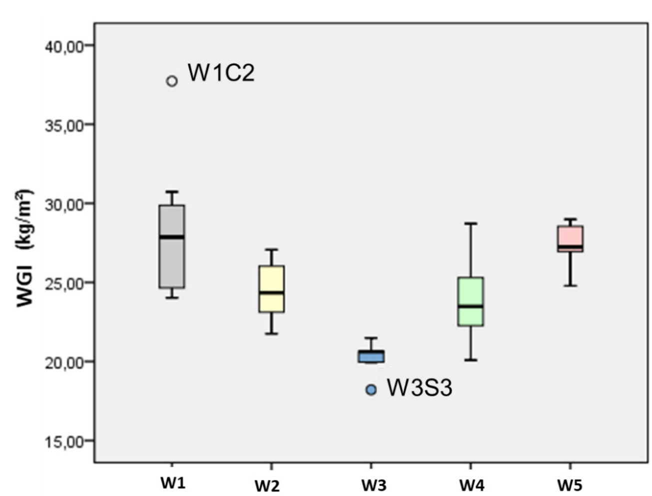

Figure 6 – Outliers in the boxplot analysis.

chase waste generation index on masonry walls. Nevertheless, extreme values for the statistic test are expected less than 5% of the time, for this study, where the confidence level is 95%.

Through linear regression, it was proven that the type of block and the type of tool used to cut chases on masonry walls for electrical installations has no significant influence on the calculated WGI (kg/m^2). The frequency of WGI values is concentrated between 23 and 29 kg/m^2, with values ranging from 26 to 29 kg/m^2, with the most incidences.

The statistically found WGI is 26.5 kg/m^2 with a standard deviation of 2.6 kg/m^2 for the chases cut on ceramic block walls. The 95% confidence interval limits range from 25.8 to 27.2 kg/m^2. Of the 56 samples used to perform a descriptive evaluation, the lowest index value was 20.1 kg/m^2 and the highest was 31.6 kg/m^2. Due to the limitations of the model, the WGI found is valid for the installation of conduits and lightboxes that do not exceed the depth of the first hole of the ceramic block. In electrical installations, there are junction boxes and electrical panels of bigger sizes than those studied in this article; these cases require separate studies. It is also possible to study the relationship between the size of the grains and the possibilities of using the waste, according to the tool used.

The results obtained by this research demonstrate the quantitative and qualitative characteristics of the waste generated when cutting chases on masonry walls to run electrical installations. The data found can also be extrapolated for hydraulic installations because it is a similar activity. However, the similarity of the dimensions of the materials used in the infrastructure must be analyzed. Estimating a WGI that considers the cutting surface area favors the use of results in the BIM environment.

Conclusions

Minimizing environmental impacts associated with the generation of construction waste involves understanding the generating processes. This study evaluated chase cutting on masonry walls to run electrical installations to understand the qualitative and quantitative aspects of the waste generated. The study demonstrated that the characteristics of the waste generated from cutting chases for electrical installations depend on the cutting technique (tool) used. The type of tool employed did not influence the waste generation index (kg/m^2). However, the tool used directly influenced the quality of the service, productivity, and the volume of waste generated.

Thus, by analyzing the indicators, it was possible to identify an opportunity to reduce waste generation with more efficient masonry cutting techniques. Considering that the form of masonry cutting has directly reflected the quantitative and qualitative aspects of the waste generated, more environmentally-friendly works can be obtained.

The tools analyzed showed differences of up to 14 times for the time required to cut a one-meter chase. The average time required to cut a one-meter chase was close to 20 seconds for the milling cutter, two minutes for the marble saw in conjunction with the chisel, and four minutes and 15 seconds for the chisel used alone.

A waste generation index of 26.5 ± 2.6 kg/m^2 was calculated under laboratory condition, and of 28.0 ± 2.2 kg/m^2 on construction sites. Considering the waste characteristics, the milling cutter had the smallest maximum dimension characteristic (9.5-19mm) and the largest bulk density (1,134 ± 31.8 kg/m^3), followed by the waste resulting from the marble saw (38-76 mm; 1,054.5 ± 31 kg/m^3, respectively) and the cold chisel (38-76 mm; 1,017.1 ± 33.7 kg/m^3, respectively). The marble saw and the cold chisel waste samples had around 78% of their composition in the coarse aggregate grain size range. The milling cutter waste samples were the finest and had on average 60% of their composition in the fine aggregate grain size range.

From this research, new fields of study emerge in environmental sciences, with the possibility of using the indicators studied in building information modeling (BIM). In conclusion, studies on construction waste generation should be encouraged as they can provide useful information to environmental managers, who can study the generation processes and reduce associated environmental impacts.

Contribution of authors:

STEFFEN, L. O.: Conceptualization; Data Curation; Formal Analysis; Funding Acquisition; Research; Methodology; Validation; Writing — Original Draft. OLIVEIRA, C. J.: Data Curation; Formal Analysis; Funding Acquisition; Program; Writing — Original Draft. SCHAMNE, A. N.: Resources; Writing — original draft; Writing — review and editing. NAGALLI, A.: Conceptualization; Methodology; Project Administration; Supervision; Validation; Writing — review and editing.

References

Abdelhamid, M. S., 2014. Assessment of different construction and demolition waste management approaches. HBRC Journal, v. 10, (3), 317-326. https://doi.org/10.1016/j.hbrcj.2014.01.003.

Adjei, S. D., 2016. Review of waste management in the UK construction industry. Thesis (Doctoring in Engineering and Science) – University of Wolverhampton, United Kingdom.

Ajayi, S. O., Oyedele, L. O., Bilal, M., Akinade, O. O., Alaka, H. A., Owolabi, H. A., Kadiri, K. O., 2015. Waste effectiveness of the construction industry: Understanding the impediments and requisites for improvements. Resources, Conservation and Recycling, v. 102, 101-112. https://doi.org/10.1016/j.resconrec.2015.06.001.

Akinade, O. O.; Oyedele, L. O.; Ajayi, S. O.; Bilal, M.; Alaka, H. A.; Owolabi, H. A.; Arawomo, O. O., 2018. Designing out construction waste using

BIM technology: Stakeholders' expectations for industry deployment. Journal of Cleaner Production, v. 180, 375-385. https://doi.org/10.1016/j.jclepro.2018.01.022.

Associação Brasileira de Normas Técnicas (ABNT), 1982. NBR 7251: Agregado em estado solto-determinação da massa unitária. ABNT, Rio de Janeiro.

Associação Brasileira de Normas Técnicas (ABNT), 1987. NBR 7217: Agregados: determinação da composição granulométrica. ABNT, Rio de Janeiro.

Associação Brasileira para a Reciclagem dos Resíduos de Construção e Demolição (ABRECON), 2020. Relatório Pesquisa Setorial 2020. ABRECON, São Paulo (Accessed April 5, 2022) at:. https://abrecon.org.br/pesquisa_setorial/.

Bakshan, A.; Srour, I.; Chehab, G.; El-Fadel, M., 2015. A field-based methodology for estimating waste generation rates at various stages of construction projects. Resources, Conservation and Recycling, v. 100, 70-80. https://doi.org/10.1016/j.resconrec.2015.04.002.

Behera, M.; Bhattacharyya, S. K.; Minocha, A. K., Deoliya, R.; Maiti, S., 2014. Recycled aggregate from C&D waste & its use in concrete–A breakthrough towards sustainability in construction sector: A review. Construction and Building Materials, v. 68, 501-516. https://doi.org/10.1016/j.conbuildmat.2014.07.003.

Biju, B.; Nagalli, A.; Moura, E., 2021. Uso do SIG auxiliado pela análise multicritério de tomada de decisão na indicação de possíveis áreas aptas para a disposição em solo de resíduos de construção civil. Revista Brasileira De Ciências Ambientais (Online), v. 56, (3), 470-479. https://doi.org/10.5327/Z21769478947.

Bossink, B. A. G.; Brouwers, H. J. H., 1996. Construction waste: quantification and source evaluation. Journal of Construction Engineering and Management, 122, (1), p. 55-60. https://doi.org/10.1061/(ASCE)0733-9364(1996)122:1(55).

Brito, J.; Pereira, A. S.; Correia, J. R., 2005. Mechanical behavior of non-structural concrete made with recycled ceramic aggregates. Cement and Concrete Composites, 27, (4), p. 429-433. https://doi.org/10.1016/j.cemconcomp.2004.07.005.

Cochran, K. M.; Townsend, T. G., 2010. Estimating construction and demolition debris generation using a materials flow analysis approach. Waste Management, 30, (11), p. 2247-2254. https://doi.org/10.1016/j.wasman.2010.04.008.

Corinaldesi, V.; Moriconi, G., 2009. Behaviour of cementitious mortars containing different kinds of recycled aggregate. Construction and Building Materials, 23, (1), p. 289-294. https://doi.org/10.1016/j.conbuildmat.2007.12.006.

Duarte, A.; Bezerra, S.; Gonçalves, E. 2021. Indicador de salubridade ambiental para avaliação de bairros em áreas urbanas: um estudo de caso em Caruaru (PE), Brasil. Revista Brasileira de Ciências Ambientais (Online), v. 56, (1), 166-179. https://doi.org/10.5327/Z21769478750.

Evangelista, A. C. J.; Tam, V. W. Y.; Santos, J., 2018. Recycled ceramic fine aggregate for masonry mortar production. Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate. Springer, pp. 1141-1148.

Fatta, D.; Papadopoulos, A.; Avramikos, E.; Sgourou, E.; Moustakas, K.; Kourmoussis, F.; Loizidou, M., 2003. Generation and management of construction and demolition waste in Greece: an existing challenge. Resources, Conservation and Recycling, 40, (1), p. 81-91. https://doi.org/10.1016/S0921-3449(03)00035-1.

Ferreira, J. C.; Patino, C. M., 2015. O que realmente significa o valor-p? Jornal Brasileiro de Pneumologia, 41, (5), p. 485-485. https://doi.org/10.1590/S1806-37132015000000215.

Formoso, C. T.; Soibelman, L.; Cesare, C.; Isatto, E. L., 2002. Material waste in building industry: main causes and prevention. Journal of Construction Engineering and Management, 128, (4), p. 316-325. https://doi.org/10.1061/(ASCE)0733-9364(2002)128:4(316).

Fraga, M. F., 2006. Panorama da geração de resíduos da construção civil em Belo Horizonte: medidas de minimização com base em projeto e planejamento de obras. Dissertation (Mastering in Civil Engineering), Programa de Pós-Graduação em Saneamento, Meio Ambiente e Recursos Hídricos, Universidade Federal de Minas Gerais, Belo Horizonte.

Frotté, C.; Di Nubila, C. S. A.; Nagalli, A.; Mazer, W.; Macioski, G.; Oliveira, L. O. S., 2017. Estudo das propriedades físicas e mecânicas de concreto com substituição parcial de agregado natural por agregado reciclado proveniente de RCD. Matéria, v. 22, (2), e11811. https://doi.org/10.1590/S1517-707620170002.0143

Galán, B.; Viguri, J. R.; Cifrian, E.; Dosal, E.; Andres, A., 2019. Influence of input streams on the construction and demolition waste (CDW) recycling performance of basic and advanced treatment plants. Journal of Cleaner Production, v. 236, 117523. https://doi.org/10.1016/j.jclepro.2019.06.354.

Gayarre, F. L.; Boadella, Í. L.; Pérez, C. L. C.; López, M. S.; Cabo, A. D., 2017. Influence of the ceramic recycled aggregates in the masonry mortars properties. Construction and Building Materials, v. 132, 457-461. https://doi.org/10.1016/j.conbuildmat.2016.12.021.

Ghisellini, P.; Ripa, M.; Ulgiati, S., 2018. Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. Journal of Cleaner Production, v. 178, 618-643. https://doi.org/10.1016/j.jclepro.2017.11.207.

Jalali, S., 2007. Quantification of construction waste amount. 6ª Jornadas Técnicas Internacionais de Resíduos, Viseu, Portugal.

Juan-Valdés, A; Rodríguez-Robles, D.; García-González, J.; Guerra-Romero, M. I.; Morán-Del Pozo, J. M., 2018. Mechanical and microstructural characterization of non-structural precast concrete made with recycled mixed ceramic aggregates from construction and demolition wastes. Journal of Cleaner Production, v. 180, 482-493. https://doi.org/10.1016/j.jclepro.2018.01.191.

Khalaf, F. M.; Devenny, A. S., 2004. Recycling of demolished masonry rubble as coarse aggregate in concrete. Journal of Materials in Civil Engineering, v. 16, (4), 331-340. https://doi.org/10.1016/(ASCE)0899-1561(2004)16:4(331).

Li, J.; Ding, Z.; Mi, X.; Wang, J., 2013. A model for estimating construction waste generation index for building project in China. Resources, Conservation and Recycling, v. 74, 20-26. https://doi.org/10.1016/j.resconrec.2013.02.015.

Liu, Q.; Xiao, J.; Sun, Z., 2011. Experimental study on the failure mechanism of recycled concrete. Cement and Concrete Research, v. 41, (10), 1050-1057. https://doi.org/10.1016/j.cemconres.2011.06.007.

Lovato, P. S.; Possan, E.; Dal Molin, D. C. C.; Masuero, Â. B.; Ribeiro, J. L. D., 2012. Modeling of mechanical properties and durability of recycled aggregate concrete. Construction and Building Materials, v. 26, (1), 437-447. https://doi.org/10.1016/j.conbuildmat.2011.06.043.

Lu, W.; Yuan, H.; Li, J.; Hao, J. J.; Mi, X.; Ding, Z., 2011. An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. Waste Management, v. 31, (4), 680-687. https://doi.org/10.1016/j.wasman.2010.12.004.

Mália, M.; Brito, J.; Pinheiro, M. D.; Bravo, M., 2013. Construction and demolition waste indicators. Waste Management & Research, v. 31, (3), 241-255. https://doi.org/10.1177%2F0734242X12471707.

Martínez, P. S.; Cortina, M. G.; Martínez, F. F., 2016. Comparative study of three types of fine recycled aggregates from construction and demolition waste (CDW), and their use in masonry mortar fabrication. Journal of Cleaner Production, v. 118, 162-169. https://doi.org/10.1016/j.jclepro.2016.01.059.

Miranda, L. F. R.; Angulo, S. C.; Careli, E. D., 2009. A reciclagem de resíduos de construção e demolição no Brasil: 1986-2008. Ambiente Construído, v. 9, (1), 57-71.

Mundstock, E.; Fachel, J. M. G.; Camey, S. A.; Agranonik, M., 2006. Introdução à Análise Estatística utilizando o SPSS 13.0. Cadernos de Matemática e Estatística Série B. Universidade Federal do Rio Grande do Sul, Porto Alegre.

Nagalli, A.; Carvalho, K. Q., 2018. Model for estimating construction waste generation in masonry building. Proceedings of the Institution of Civil Engineers – Waste and Resource Management, v. 172, (1), 28-36. https://doi.org/10.1680/jwarm.18.00016.

Poon, C. S.; Ann, T.W.; Ng, L. H., 2001. On-site sorting of construction and demolition waste in Hong Kong. Resources, Conservation and Recycling, v. 32, (2), 157-172. https://doi.org/10.1016/S0921-3449(01)00052-0.

Scalone, P.; Souza, S.; Figueiredo, E., 2016. Gerenciamento de resíduos de construção civil: estudo de caso em empreendimentos comercial e residencial em Londrina (PR). Revista Brasileira de Ciências Ambientais (Online), (40), 95-106. https://doi.org/10.5327/Z2176-947820168014.

Seo, S.; Hwang, Y., 1999. An estimation of construction and demolition debris in Seoul, Korea: waste amount, type, and estimating model. Journal of the Air & Waste Management Association, v. 49, (8), 980-985. https://doi.org/10.1080/10473289.1999.10463863.

Shahidan, S.; Azmi, M. A. M.; Kupusamy, K.; Zuki, S. S. M.; Ali, N., 2017. Utilizing Construction and Demolition (C&D) Waste as Recycled Aggregates (RA) in concrete. Procedia Engineering, v. 174, 1028-1035. https://doi.org/10.1016/j.proeng.2017.01.255.

Shi, J.; Xu, Y., 2006. Estimation and forecasting of concrete debris amount in China. Resources, Conservation and Recycling, v. 49, (2), 147-158. https://doi.org/10.1016/j.resconrec.2006.03.011.

Skoyles, E. R., 1976. Materials wastage: a misuse of resources. Building Research and Practice, v. 4, (4), p. 232-243. https://doi.org/10.1080/09613217608550498.

Tanaka, G. M.; Costa, M. R. M. M.; Silva, N. G.; Dyminski, A. S., 2010. Efeitos do tipo de areia de resíduo de construção e demolição (RCD) nas propriedades de argamassa de cimento e areia. Encontro Nacional de Tecnologia do Ambiente Construído, 13.

Tavira, J.; Jiménez, J. R.; Ayuso, J.; López-Uceda, A.; Ledesma, E. F., 2018. Recycling screening waste and recycled mixed aggregates from construction and demolition waste in paved bike lanes. Journal of Cleaner Production, v. 190, 211-220. https://doi.org/10.1016/j.jclepro.2018.04.128.

Wu, Z.; Yu, A. T. W.; Shen, L.; Liu, G., 2014. Quantifying construction and demolition waste: an analytical review. Waste Management, v. 34, (9), 1683-1692. https://doi.org/10.1016/j.wasman.2014.05.010.

Yost, P. A.; Halstead, J. M., 1996. A methodology for quantifying the volume of construction waste. Waste Management & Research, v. 14, (5), 453-461. https://doi.org/10.1006/wmre.1996.0044.