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Quantitative and qualitative study of waste produced by civil construction of masonry in the South of Minas Gerais and comments on sustainability

Estudo Quantitativo e Qualitativo da Produção de Resíduos Sólidos na construção civil em alvenaria no Sul de Minas Gerais com comentários sobre sustentabilidade

Estudio cuantitativo y cualitativo de la producción de residuos sólidos en construcción civil de albañilería en el Sur de Minas Gerais con comentarios sobre sustentabilidad

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Abstract
Historically and still in current times, bricks are easy to be manufactured due to vast geological resources, are versatile as a building material, support loads well and show good aesthetics, however, they generate environmental problems due to waste disposal, high energy consumption in manufacturing with high CO_2 production and high-water consumption in construction in the manufacturing of mortar. Hypothetically, due to artisanal production and poorly qualified labor in Brazil for civil construction, mainly masonry, it is expected to find inadequate disposal of solid waste in civil construction. Therefore, the management of solid waste disposal from civil construction deserves special attention and must be inspected. This work showed that the disposal of solid waste in construction in small urban centers in the South of Minas Gerais occurs irregularly approximately 89% of cases, generating problems of obliteration of sidewalks and reduction of parking area with possible movement of this waste on public roads. In general terms, inadequate storage and waste disposal represent a problem and even a setback in sustainability actions in civil construction that does not reflect the appeal of today's society that seeks improvements for better living conditions for the planet. Due to the small amount of sampling and the type (small urban centers), more studies need to be carried out to see if the high percentage of solid waste allocation in civil construction also occurs in this way in other regions, and studies in large urban centers could be done for data comparison.
Keywords: Civil engineer; Sustainability; Solid residues.

Resumo
Historicamente e ainda nos tempos atuais, os tijolos são fáceis de serem fabricados devido aos vastos recursos geológicos, são versáteis como material de construção, suportam bem cargas e apresentam boa estética, no entanto, eles geram problemas ambientais devido ao descarte de resíduos sólidos, alto consumo de energia na construção com alta produção de CO_2 e consumo de água na construção na fabricação de argamassas. Hipoteticamente, devido à produção artesanal e à mão de obra pouco qualificada no Brasil para a construção civil, principalmente a alvenaria, espera-se encontrar destinação inadequada de resíduos sólidos na construção civil. Portanto, o gerenciamento da destinação de resíduos sólidos da construção civil merece atenção especial e deve ser fiscalizado. Este trabalho mostrou que o descarte de resíduos sólidos em construção em pequenos centros urbanos do Sul de Minas Gerais ocorre de forma irregular em aproximadamente 89% dos casos, gerando problemas de obliteração de calçadas e redução de área de estacionamento com possível movimentação desses resíduos em vias públicas. Em linhas gerais, o armazenamento e a destinação inadequada de resíduos representam um problema e até mesmo um retrocesso nas ações de sustentabilidade na construção civil que não reflete o apelo da sociedade atual que busca melhorias para melhores condições de vida para o planeta. Devido ao pequeno quantitativo de amostragem e ao tipo (pequenos centros urbanos), mais estudos precisam ser realizados para verificar se o alto percentual de destinação de resíduos sólidos na construção civil ocorre desta forma

também em outras regiões, e estudos em grandes centros urbanos. centros poderiam ser feitos para comparação de dados.
Palavras-chave: Engenharia civil; Sustentabilidade; Resíduos sólidos.

Resumen
Históricamente y aún en la actualidad, los ladrillos son fáciles de fabricar debido a los vastos recursos geológicos, son versátiles como material de construcción, soportan bien las cargas y muestran buena estética, sin embargo, producción de CO_2 y alto consumo de agua en la construcción en la fabricación de morteros. Hipotéticamente, debido a la producción artesanal y la mano de obra poco calificada en Brasil para la construcción civil, principalmente mampostería, se espera encontrar una disposición inadecuada de desechos sólidos en la construcción civil. Por tanto, la gestión de la disposición de residuos sólidos de la construcción civil merece una atención especial y debe ser inspeccionada. Este trabajo mostró que la disposición de residuos sólidos en construcción en pequeños núcleos urbanos del sur de Minas Gerais ocurre de manera irregular aproximadamente en el 89% de los casos, generando problemas de obliteración de aceras y reducción de área de estacionamiento con posible movimiento de estos residuos en la vía pública. En términos generales, el almacenamiento y disposición de residuos inadecuados representan un problema e incluso un retroceso en las acciones de sustentabilidad en la construcción civil que no refleja el atractivo de la sociedad actual que busca mejoras para mejores condiciones de vida para el planeta. Debido a la pequeña cantidad de muestreo y al tipo (pequeños centros urbanos), es necesario realizar más estudios para ver si el alto porcentaje de asignación de residuos sólidos en construcción civil también ocurre de esta manera en otras regiones, y estudios en grandes áreas urbanas. Se podrían hacer centros para la comparación de datos.
Palabras clave: Ingeniería civil; Sustentabilidad; Residuos sólidos.

1. Introduction

The conventional masonry system is as old as the use of brick, dating to approximately 7000 BC (Murmu & Pattel, 2018; Neumann, 2017), this was and still is, in most small and medium-sized buildings (Lai, 2016), a craft task, facilitated by machines and implements that speed up the labor and tend to increase the quality of the civil construction product, especially in the last two decades of the 20th century (Meira & Araújo, 2016).

However, errors are made, in calculations, in execution, human errors that cause the construction material to become unusable, which will then be discarded and can even generate pathologies in the constructions after they are done (Souza & Ripper, 1998). Within this scope, despite changes to optimize constructions, there is still a high production of waste and material waste in masonry constructions (Rocha, 2006), but these can be minimized in drywall constructions made with steel frame and wood frame (Resende et al., 2021a; Aversi-Ferreira, 2018).

Historically and still in current times, bricks are easy to be manufactured due to vast geological resources, are versatile as a building material, support loads well and show good aesthetics, however, as mentioned above, they generate environmental problems (Coletti et al., 2016) due to waste disposal, high energy consumption in manufacturing with high CO2 production and high-water consumption in construction in the manufacturing of mortar.

The causes of waste production in civil construction are many, coming from renovations, demolitions and lack of efficient management of those involved in the work and inspection agencies. Perhaps the main problem is a failure of environmental awareness by the builders and the population (Capaz & Nogueira, 2014).

The lack of projects with a sustainable focus on civil construction in masonry results in environmental damage that can be irreparable when using non-renewable raw materials, energy consumption of organic origin in the transport of material and in the processing of materials (Schinini, Bagnati & Cardoso, 2004).

Brazil has a culture of masonry construction due to the heritage of Portugal, where brick constructions predominate to this day (Gouveia, 2007) due to the scarcity of forests in that country (Aversi-Ferreira, 2018).

In fact, wood follows human constructions since antiquity and even older than the use of bricks, however, it wears out faster. However, it can be handled more easily and quickly with a high strength-to-weight ratio (Resende et al., 2021a; Pfeil &

Pfeil, 2003; Molina & Calil, 2010). Currently, with wood derived from reforestation, this becomes one of the alternatives for more sustainable civil construction (Aversi-Ferreira, 2018).

As an alternative, steel frame-type steel constructions have advantages in terms of sustainability and thermo-acoustic comfort (for more details, see Aversi-Ferreira, 2018). These two types of construction mentioned, regardless of the cost/benefit in relation to masonry, are unquestionably more sustainable and less harmful to the environment.

Despite the appeal of sustainability and engineering companies are striving to improve constructions to make them more sustainable (Capaz & Nogueira, 2014), the production of waste in masonry constructions is an unresolved problem, especially if we consider the handling and management of solid civil construction waste, derived not only from constructions, but from repairs, renovations, demolitions and land excavations (Capaz & Nogueira, 2014).

The guidelines for the management of solid waste derived from civil engineering activities are regulated by CONAMA resolutions numbers 307/2002, 348/2004, 431/2011 and 448/2012, which classify waste into four classes:

I. Class A - Reusable or recyclable waste as aggregates;

II. Class B - Recyclable waste for other purposes such as plastics, paper, cardboard, metals, glass, wood and plaster;

III. Class C - Waste for which economically viable applications or technologies that make its recovery or recycling possible haven't been developed.

IV. Class D - Hazardous waste from the construction process, such as paints, solvents, oils and others or those contaminated or harmful to health from demolitions, renovations, repairs of radiological clinics, industrial facilities and others, as well as tiles from other objects and materials that contain asbestos or other products harmful to health (Capaz & Nogueira, 2014).

Hypothetically, due to artisanal production and poorly qualified labor in Brazil for civil construction, mainly masonry, it is expected to find inadequate disposal of solid waste in civil construction, especially in small and medium-sized works where masons take over.

Therefore, the management of solid waste disposal from civil construction deserves special attention and must be inspected. Considering this, a quantitative and qualitative study of the disposal of civil construction waste was carried out in the cities of Três Corações, Itamonte, São Lourenço, Carmo da Cachoeira, Alfenas and Varginha to verify the disposal of civil construction waste according to CONAMA standards and NR 18, mainly, and an effort was made to associate disposal with sustainable possibilities with proposals for improvement.

2. Methodology

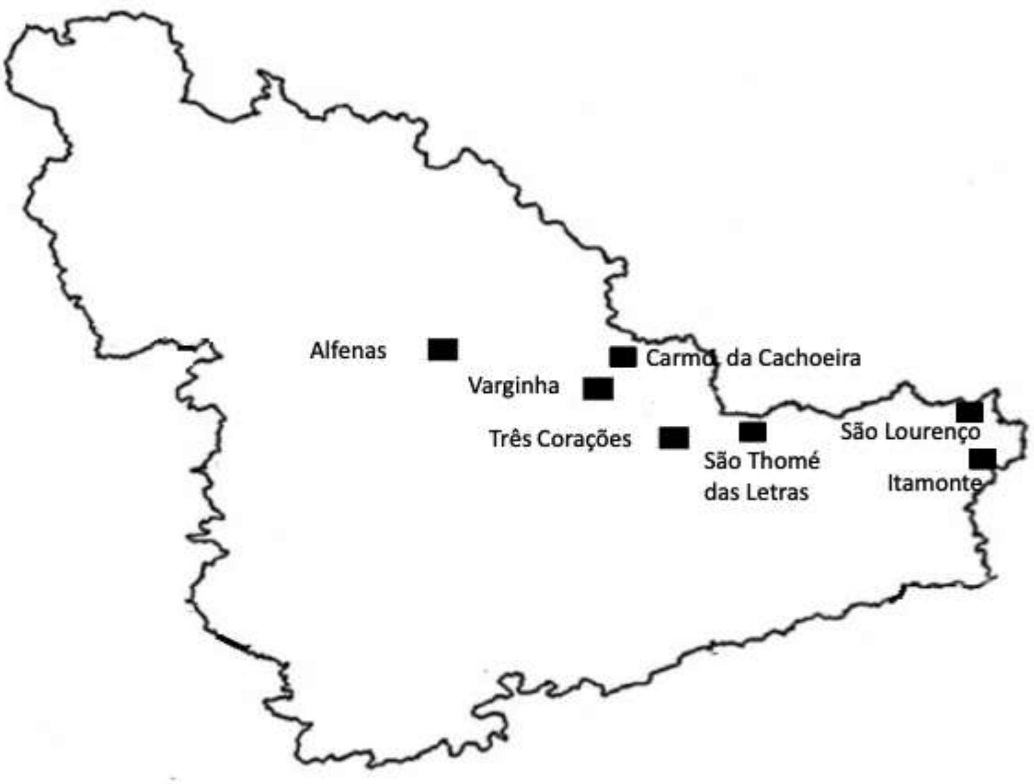
A local study of the construction works was carried out to photograph the waste generated in these works, sought at random. 112 works were visited in the cities of Três Corações, São Tomé das Letras, Carmo da Cachoeira, Varginha, Itamonte, São Lourenço and Alfenas in southern Minas Gerais (Table 1, Figure 1).

Table 1. Main information about the studied municipalities in this work.

Municipalities	**Number approximated of habitants [x1000]**	**Area [km^2]**	**Altitude [m]**	**Main economic activities**
Três Corações	80	828.038	839	Agriculture of coffee, corn, potatoes, beans, rice and regional fruits
São Thomé das Letras	7	369.515	1440	Stone Mining and Tourism
Carmo da Cachoeira	12	506	959	Coffee agriculture and milk production
Varginha	134	395.396	980	High Quality Coffee Farming
Itamonte	16	430.597	933	Tourism, agriculture and milk production
São Lourenço	46	58.019	950	Tourism and commerce
Alfenas	80	850.446	888	Agro-pastoral and coffee production

Source: sites of the cities Alfeans, São Lourenço, Itamonte, Varginha, Carmo da Cachoeira, Sao Thomé das Letras e Três Corações (2021).

Figure 1. South of Minas Gerais' map indicating the position of studied cities in this work.



Source: Modification from Saes, Gambi & Curi (2016) and Google maps.

The count of construction sites visited was made by city in the neighborhoods and urban centers, and those that did not follow the methods of storage and disposal of solid waste were classified by the following:

a. Constructions without fence or siding;

b. Material without containment bays and/or on sloping ground;

c. Material placed on the street, sidewalk or in attached lots;

d. Disposal of material without the use of an appropriate dumpster.

These data were verified, cataloged and used to perform the statistical tests.

The items analyzed [a. Constructions without fence or siding; b. Material without containment bays and/or on sloping ground; c. Material placed on the street, sidewalk or in attached lots; d. Disposal of material without the use of an appropriate dumpster] were based on CONAMA standards, resolutions numbers 307/2002, 348/2004, 431/2011 and 448/2012, NR 9 and NR 18, which regulate the isolation of the work and the processes of storage and disposal of materials, as the lack of proper waste management generates accumulation on public roads or is washed by rainwater, spreading them and taking them to rivers and canals.

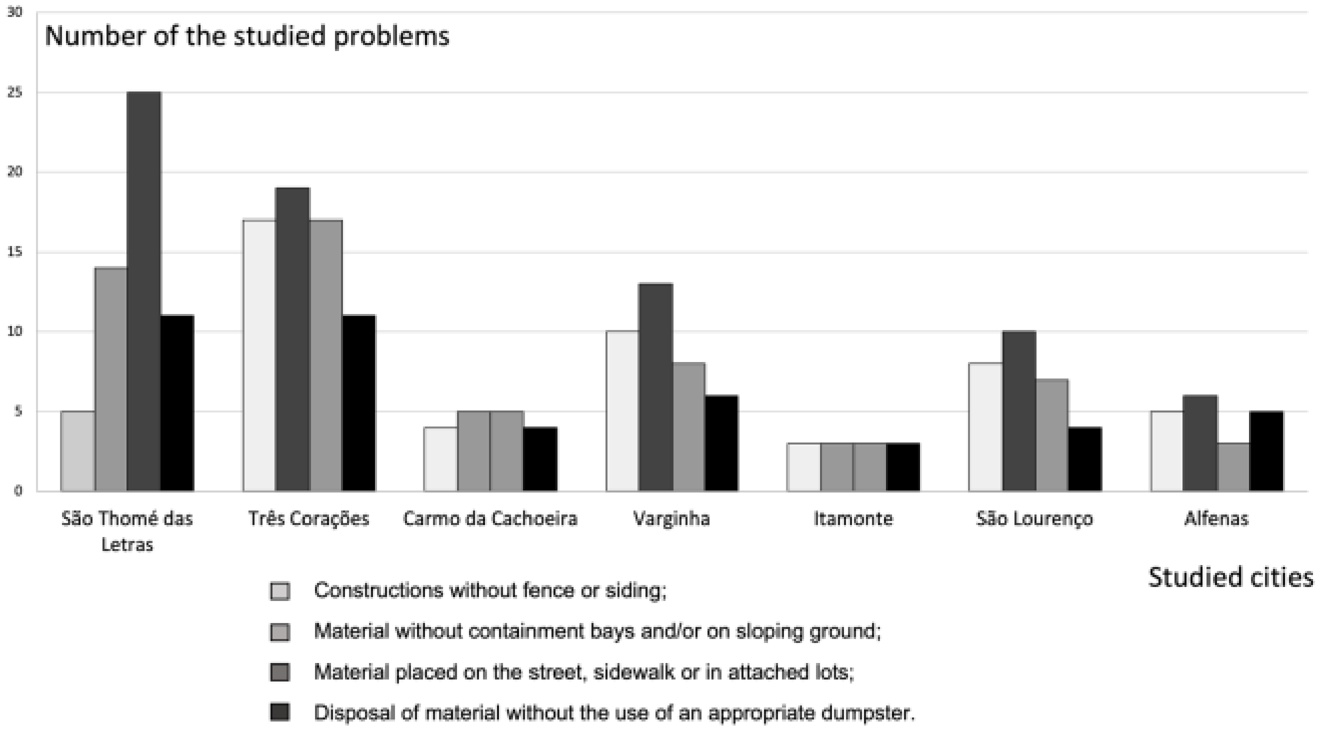
The results were plotted and the $\chi 2$ test was applied to compare the expected and observed data for the items mentioned for $p<0.05$. It is important to mention that a work may have more than one undesirable item. A linear regression analysis was performed for each item by city for $p<0.05$. To clarify, the expected data are all correct applications of the CONAMA rules, and the undesirable ones are those that do not follow the CONAMA regulation and liable of fine. Indeed, the $\chi 2$ test applied here furnish data to verify the distance among the constructions that followed the CONAMA rules and the other that do not those regulations.

As the data obtained did not come from relationships with human beings and no photos were taken inside the construction sites, authorization from an ethics committee was not required.

3. Results and Discussion

Twenty construction works were observed and photographed in São Thomé das Letras, 25 in Três Corações, 12 in Carmo da Cachoeira, 24 in Varginha, 7 in Itamonte, 17 in São Lourenço and 13 in Alfenas (Figure 3).

Figure 2. Problems verified in the Civil constructions in the studied cities in this work. For each city, from left to right, the problems analysed were: Constructionsd without fence or siding; Material without containment bays and/or on sloping ground; Material placed on the street, sidewalk or in attached lots; Disposal of material without the use of an appropriate dumpster.



Source: Authors.

In quantitative terms, differences were observed in absolute numbers and statistics in the non-application of waste management standards in civil construction [CONAMA, NR 18] between cities and items according to the $\chi 2$ test for $p<0.05$ (figure 2) and the linear regression calculation for $p<0.05$ with the values of R2 are shown in Figure 3. The analyzed items were those cited above from the CONAMA and NR 18, i.e., constructions without fence or siding; material without containment bays and/or on sloping ground; material placed on the street, sidewalk or in attached lots and; disposal of material without the use of an appropriate dumpster.

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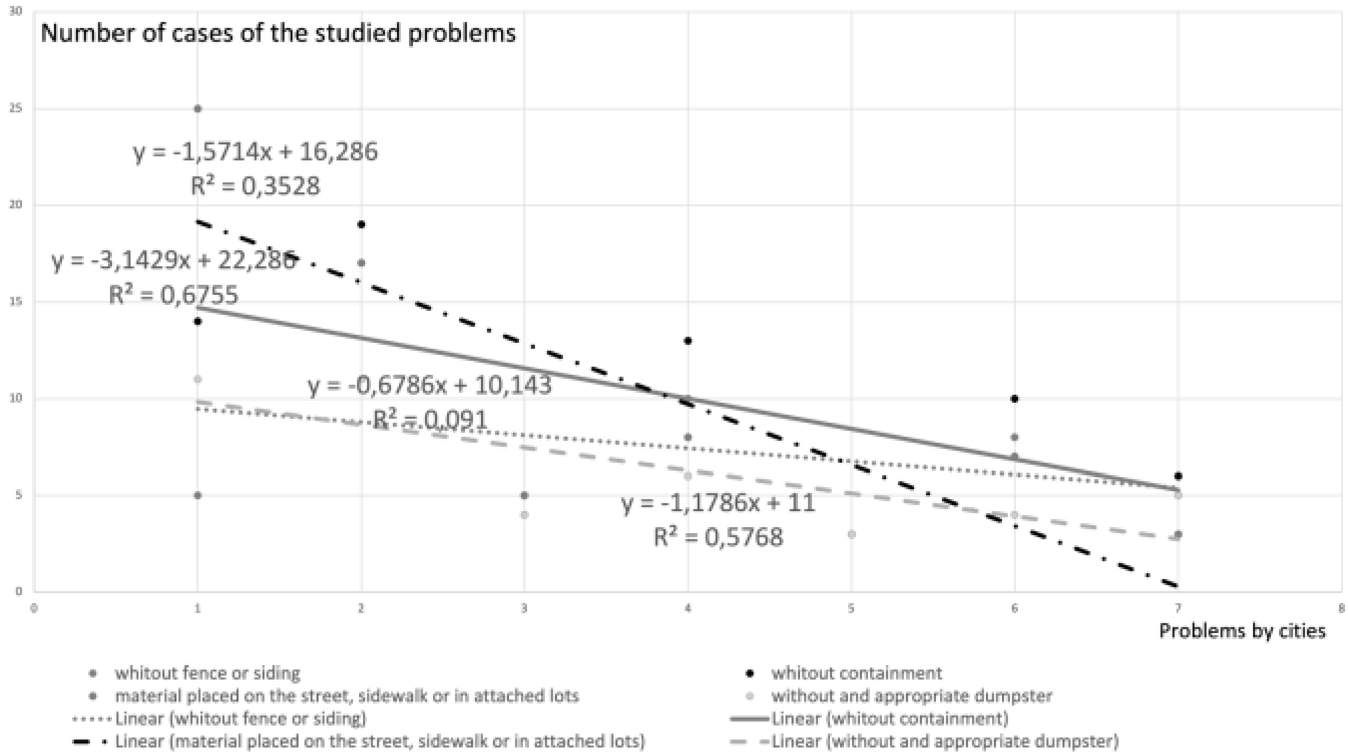
Figure 3. Linear regression analysis between items studied by city with equations and R2 values. There was no strong linear correlation between the non-application of standards for any of the items in the various cities.



Source: Authors.

In qualitative terms, the dangers of not complying with the standards were widely verified mainly with the placement of material in streets and sidewalks and outside isolation bays, in all cases for medium-sized constructions. In large constructions the safety items studied here happened rarely, only 3/112 in all cities (figure 4D).

In some cases, the danger of landslides was evident due to the lack of material insulation and the slope of the land (Figure 4A) and materials without containment that could cause people to fall due to the effect of sand, cement and stones on the floor (figures 4B and 4C).

Figure 4. Some photos of the works studied in this work. A. Observe stacked bricks with no support base on sloping terrain. B. Solid waste on side terrain and no bucket, bricks stacked on sidewalk on steep ground, with paint cans [Type D waste]. C. Solid waste disposed on the street and sidewalk along with uninsulated sand [Type B waste]. D. A large construction case with siding without waste and off-site material.

Source: Authors.

Considering the data obtained, non-compliance with basic rules for disposing of material in works occurred in more than 80% of the cases studied (figure 2) and it should be emphasized that observations inside the work such as the use of protective materials, fire extinguishers fire, bathroom and drinking fountains for employees were not included in this study.

The $\chi 2$ analysis showed that there was no parameter that stood out the most, as the null hypothesis was rejected, ie, the relationship between the items studied in the different cities did not remain constant or similar, which was corroborated by the linear regression within the items themselves, also when considering cities (figure 3). In this case, the smallest relation was observed for the item “without fences or siding” with R2 = 0.091 and the largest relation occurred for the item “without stalls or insulation” with R2 = 0.6755 (figure 3). Considering the group data and linear regression, the least obeyed parameter in the works was “without stalls or isolation” both for class B waste in the majority and for class D, mainly paint cans on the waste (figure 4).

In general, the non-compliance with the normative parameters can indicate negligence, lack of engineers commanding the work, lack of supervision in small and medium-sized works, because in large works the items studied were observed, so it is reasonable to think that large-scale works receive more attention from inspections, or the seriousness of accidents can have a stronger impact on society which forces owners to avoid them.

In epistemological terms, this study can be addressed as a problem that reproduces the questions, uncertainties and possibilities of a context in the association of Brazilian civil construction in relation to processes of a sustainable nature in consolidation in the world. It was a study whose conclusions are of an empirical and quantitative nature, which investigated the behavior of the Brazilian construction industry in small towns that may represent almost the entire country, but not the large centers.

This is a descriptive case analysis (Yin, 2001; Voss et al., 2002) that allows the knowledge of the process (Gil, 1996; Berto; Nakano, 2000), via search, research and study of a problem not completely clear within the path of sustainability. Despite the certainty of the errors evidenced in the disposal of solid waste, it is not possible to reach the conclusion of the specific reasons for illegality, just understand the problem in general terms and suppose the reason for the set of decisions that were taken (Yin, 2001), as not all normative parameters were observed.

The scenario where a process takes place is the basis for understanding it, in fact, the perspective of the Brazilian scenario in the civil construction sector fosters economic, social and environmental issues (Vieira, 2006) through its own production process, as it occurs through construction from small itinerant factories on construction sites, ie, the construction industry goes to the customer and works in a different location from their address, having to transport inputs and machinery to the construction site (Salgado, 2014).

However, despite this process, the construction sector indirectly indicates the financial growth of a country that increases in times of financial resources and decreases in times of crisis, and, in the case of Brazil, masonry constructions indicate greater industry profit cement, ceramics, potteries that grow together with the buildings.

According to the type of masonry construction, the more constructions, the greater the production of waste (Campos, 2006), the greater the use of water, the more use of cement whose production generates high doses of CO2 and heat, the more use of steel, the greater removal of soil, and therefore greater effect on the environment, it is a fact that civil construction is the largest consumer of natural resources on the planet (Sjostrom, 1992).

All constructions generate waste (Zaparte, 2014) whose quantity depends on the size and type of construction. Sustainable constructions, such as drywall, steel frame, wood frame, generate less waste than traditional masonry constructions (Aversi-Ferreira, 2018), as the industry is not located at the construction site, the building is only assembled with material coming directly from the factory, therefore, with fewer manufacturing defects and much less waste.

The generation of waste brings a social concern within the scope of sustainability, not only for large companies that generate a lot, but for the sum of medium and small constructions. Most of the amount of waste generated is a consequence of the inefficiency of the work execution processes, lack of qualification, management tools and old processes still applied in civil construction, observed for more than 40 years (Resende et al., 2021a; Aversi- Ferreira, 2018; Bruna, 1976). B and D (Leite et al., 2010, Ângulo et al., 2013) (figure 4A, 4B and 4C), as can be seen in this work, in which most of the works in all the cities studied presented inadequate disposal and storage of solid waste with a mixture of different types of disposal classes in the same space with a predominance of classes B and D (Leite et al., 2010, Ângulo et al., 2013) (figure 4A, 4B and 4C)..

Civil construction waste comes, in addition to construction processes, from renovations, demolitions, repairs and land excavations; activities already established by Conama Resolutions numbers 307/2002, 348/2004, 431/2011 and 448/2012, which propose that each generator is responsible for recycling and proper final disposal within the standards. The law also establishes that States and Municipalities have until 2022 to prepare and update waste management plans (BRASIL, 2010). In this study, all residues were verified in construction processes, not demolitions, which can be explained by the fact that demolitions are rare in small centers.

Another problem associated with the production of waste is the irregular disposal of these wastes in cities representing 50% of the mass of urban solid waste in Brazil (BRASIL, 2005b), overloading the municipalities' public cleaning systems, however, our data showed that this occurred in most works (figure 2).

This situation causes access impediments to sidewalks and part of the street, reducing the parking area and allows the movement of material to be used, such as sand and smaller gravel and residues that can move by the action of rainwater and carry the material to riverbeds and canals, contaminating them (figure 4A, 4B and 4C).

Solid waste that is not discarded or incorrectly allocated can be a source of accidents with venomous animals such as snakes and scorpions, putting animal and human health at risk, in addition to what areas with low light can allow. There can also be proliferation of bacteria and fungi, retaining viruses, some of which may be pathological, which is in disagreement with the requirements of the Environmental Risk Prevention Program (PPRA), NR-9 of 12/29/1994.

Class D residues have a certain toxicity, and their movement spreads this toxicity in addition to providing contact with humans and animals, especially children and dogs, but this does not rule out that contact with humans creates danger in relation to class B, as it can hurt people who try to manipulate them, such as those who work looking for useful material in the waste or even the workers at the construction site. In fact, being responsible for putting any person in a situation of danger is punishable by article 132 of the Brazilian Penal Code.

Effective inspection can reduce the allocation of civil construction materials in prohibited areas and waste outside the dumpsters, on sidewalks, streets or on lateral land.

Part of the solution for reducing solid waste is the change from traditional construction processes to sustainable ones, which is happening slowly in Brazil (Aversi-Ferreira, 2018). However, at least in palliative terms, directing waste to suitable locations already is a good procedure.

As it is difficult to quickly change entrenched and conservative behaviors (Aversi-Ferreira, 2018), among others due to the low qualification of the construction workforce in the country, making masonry construction more sustainable seems to be a more viable solution than a sudden change for drywall-type constructions for which the country is not prepared, mainly due to the lack of qualified labor (Resende et al., 2021a; Aversi-Ferreira 2018).

Rainwater storage in gallons and boxes at the construction site can help saving and sustainability in construction, as well as well-designed projects (in this case, design with engineers) that avoid rework and therefore have less waste. For example, there are few, but there are construction waste recycling plants that should be used making the disposal process more in line with sustainability standards in civil construction.

Besides, using more efficient materials in thermoacoustic terms such as expanded clay can also make the masonry lighter by reducing the amount of concrete in the foundations (Resende et al., 2021b); the use of plasterboard on the internal walls, the use of Styrofoam on the slabs reduces its weight, further helping to reduce the weight of the structure; recycle the generated waste to use it in relation to the natural ones to avoid the natural extraction of the latter.

The economy/quality relationship is part of the construction process, considering health, environmental quality and public acceptance in order to create sustainable urban structures (Neumann, 2017). In this sense, this study showed that the three items were not verified, as incorrect allocation and disposal of poorly managed waste can cause animal and human health problems, diminishing environmental quality.

4. Conclusion

This work showed that the disposal of solid waste in construction in small urban centers in the South of Minas Gerais occurs irregularly approximately 89% of cases, generating problems of obliteration of sidewalks and reduction of parking area with possible movement of this waste on public roads. Residues are not properly separated with a mixture of classes B and D, mainly allocated together. In general terms, inadequate storage and waste disposal represent a problem and even a setback in sustainability actions in civil construction that does not reflect the appeal of today's society that seeks improvements for better living conditions for the planet.

Due to the small amount of sampling and the type (small urban centers), more studies need to be carried out to see if the high percentage of solid waste allocation in civil construction also occurs in this way in other regions, and studies in large urban centers could be done for data comparison.

This work indicates that greater inspection by public agencies needs to be carried out to avoid the problems of storage and disposal of civil construction waste.

The direction for sustainability and compliance with CONAMA, NR 9 and NR 18 standards, at least, may indicate a change in the normal masonry construction process in a direction for environmental protection and the health of people and animals and/or start a process of more sustainable and ecologically beneficial constructions such as drywall constructions.

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