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Carbon footprint of the foundation work for a public building in Rio Grande do Sul, Brazil

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RESUMO: O setor da construção desempenha um papel significativo no avanço do desenvolvimento econômico e social, sendo também responsável por um elevado consumo de recursos naturais e pela emissão de grandes quantidades de dióxido de carbono. Assim, o objetivo desta pesquisa foi determinar as emissões de dióxido de carbono de uma obra de fundação e analisar a neutralização por meio do plantio de árvores. A metodologia envolveu o levantamento qualitativo e quantitativo de uma obra de fundação do estado do Rio Grande do Sul / Brasil, com duas combinações de fatores de emissão, uma nacional e outra internacional. Os resultados foram avaliados e discutidos, bem como as emissões encontradas foram analisadas frente a neutralização. O estudo revelou que a combinação internacional apresentou a maior emissão, atingindo 22,286 tCO_2, enquanto a combinação nacional teve a menor, com 17,850 tCO_2. Os materiais se mostraram como a principal fonte de emissão, seguidos por equipamentos e transporte, com médias de 89,50%, 7,67% e 2,83%. Para compensar as emissões do projeto, seria necessário plantar 98 e 122 árvores, dependendo do cenário nacional ou internacional, ocupando uma área de 0,059 a 0,073 hectares, respectivamente. Essas análises e resultados são cruciais para engenheiros que buscam compreender e reduzir o impacto ambiental de suas obras, alinhando-se com a Agenda Ambiental, Social e de Governança das empresas, os Objetivos de Desenvolvimento Sustentável da ONU que devem ser alcançados até 2030 e a transição para uma economia de baixo carbono.

PALAVRAS-CHAVE: Pegada de carbono, neutralização de emissões, construção civil, fundações.

ABSTRACT: The construction sector plays a significant role in advancing economic and social development, but it is also responsible for a high consumption of natural resources and the emission of large quantities of carbon dioxide. The aim of this research was therefore to determine the carbon dioxide emissions of a foundation project and to analyze how they could be neutralized by planting trees. The methodology involved a qualitative and quantitative survey of a foundation project in the state of Rio Grande do Sul / Brazil, with two combinations of emission factors, one national and the other international. The results were evaluated and discussed, and the emissions found were analyzed in relation to neutralization. The study revealed that the international combination had the highest emissions, amounting to 22.286 tCO_2, while the national combination had the lowest, with 17.850 tCO_2. Materials proved to be the main source of emissions, followed by equipment and transportation, with averages of 89.50%, 7.67% and 2.83%. To offset the project's emissions, it would be necessary to plant 98 and 122 trees, depending on the national or international scenario, occupying an area of 0.059 to 0.073 hectares, respectively. These analyses and results are crucial for engineers seeking to understand and reduce the environmental impact of their work, in line with the companies' Environmental, Social and Governance Agenda, the UN Sustainable Development Goals to be achieved by 2030 and the transition to a low-carbon economy.

KEYWORDS: Carbon footprint, emissions neutralization, civil construction, foundations.

1 INTRODUCTION

The construction sector plays a significant role in advancing economic and social development, and is also responsible for a high demand for natural resources and the emission of large amounts of carbon dioxide (Cheng; Cao; Jaya Mendrofa, 2021). Rock *et al.* (2020) highlight that this industry is responsible for around 40% of global carbon emissions and, currently, there is worldwide awareness about the need to reduce emissions from civil construction where several countries have implemented measures and targets in this regard (Räihä *et al.*, 2024). In the Paris Agreement, ratified by Brazil in 2015, the country committed to ambitious goals such as reducing its Greenhouse Gas (GHG) emissions by 37% by 2025, taking 2005 levels as a reference, and 43% by 2030 (Federative Republic of Brazil, 2015). Reducing carbon emissions in the construction sector is recognized as a priority due to the high quantity produced and the great potential for reduction (Zhu *et al.*, 2022).

Carbon emissions associated with the life cycle of buildings can be divided into two distinct categories: embodied emissions (raw material extraction and processing, product manufacturing, construction, and demolition) and operational emissions (cooling, heating, ventilation, lighting and household appliances), as reported by Ibn-Mohammed *et al.* (2013). Studies, such as that by Fenner *et al.* (2018), have demonstrated that, for buildings, operational carbon emissions play a significant role in life-cycle emissions. However, there is a growing trend towards reducing these emissions, driven by the promotion of energy efficiency, the implementation of clean energy sources and the development of advanced techniques, as mentioned by Acha *et al.* (2018), Moran, Goggins, and Hajdukiewicz (2017), and Rivera, MacLean, and McCabe (2021). In Brazil, geothermal air conditioning has increasingly been the subject of study for large-scale implementation to help solve this problem (Mazzutti; Faro; Klamt, 2023).

On the other hand, embodied carbon emissions are gradually gaining importance, as highlighted by Moncaster *et al.* (2019) and Zhong *et al.* (2021), which are sometimes not correlated with operational impacts (Hoxha *et al.*, 2017). Furthermore, in the case of the construction phase, the foundation, which is the structural element of the building that transfers the loads to the ground, is rarely evaluated environmentally by engineers, in addition to there being little research that investigated its emission, despite it being significant (Luo; Sandanayake; Zhang, 2019).

Therefore, the objective of the research was to develop an analysis of emissions from a Brazilian foundation work and incorporated neutralization analyzes through the planting of trees. In this way, essential information was provided for making strategic decisions in the design and construction phase, aiming to promote more sustainable practices. This reflects the research's concern with socio-environmental issues, contributing to the goals of the Paris Agreement.

2 METHODOLOGY

To inventory carbon dioxide emissions, foundation work from a public building in the state of Rio Grande do Sul / Brazil was used. This had an area of 689.857 m², where 41 continuous helix type piles were distributed.

2.1 Data collection

Data collection on consumption of civil construction materials, transport and use of equipment were obtained as follows:

- Steel: the total consumption of longitudinal bars, stirrups and annealed wire for lashings was surveyed, considering the respective gauges, by consulting the purchase invoice;
- Machined concrete: the total consumption of concrete used was determined by consulting the purchase invoice;
- Transport of steel, concrete, continuous propeller drill and backhoe: the tare weight of the delivery trucks was consulted on a plate fixed to the vehicle chassis. Regarding the weight of the load, for steel, the amount from the invoice was used; for concrete, the quantity acquired was divided by the number of trips made, obtaining the average per trip; and for equipment, their tare weights were considered, also found on plates fixed to the chassis. The distance traveled was determined using Google Maps, using the shortest route

between the work and the contracted suppliers. The type of fuel used was identified through consultation with drivers;

- Concrete pump trucks and dump trucks: the weights of the vehicles were identified on plates fixed to the chassis and the type of fuel was found by consulting the drivers. For the concrete pump truck, the fuel consumption was adopted according to Mazzutti (2023), the distance traveled was found through a route drawn on Google Maps and the number of trips was identified by measurement on site. Finally, the weight of the dump truck loads was allocated to the average according to the measurement carried out and the working time of the pump truck was determined as the concreting time provided in the report of the continuous propeller drilling machine;
- Continuous flight auger drill: the time of use was found by consulting the equipment report, adding up the time spent excavating and concreting all the piles. Fuel consumption was adopted according to Mazzutti (2023) and the weight was identified by consulting the plate fixed to the chassis;
- Backhoe: the time of use was measured on site considering the working time to remove the excavated soil, the fuel consumption was adopted according to Mazzutti (2023), and the weight was allocated to that identified on a plate fixed to the chassis.

2.2 Characteristics of the work

The project included 6 piles measuring 0.40 m in diameter and 7 m deep, with 15 stirrups measuring 0.05 m in diameter and 1.05 m in length, and 6 bars measuring 3.00 m in length and 0. 10 m in diameter. The other 35 piles were 0.50 m in diameter and 7 m deep, with 15 stirrups of 0.50 m in diameter and 1.35 m long, and 6 bars 3.00 m long and 0.10 m in diameter. Therefore, the main quantities and characteristics required to enter the Emissions Calculator for materials, transport and equipment are presented in Table 1, 2 and 3.

Table 1. Quantity of materials (Authors, 2024).

Material specification	**Specification of use**	**Quantity of material (t)**
Concrete 25 MPa	Concreting the foundations	166.557
1.25 mm annealed wire	Lashing bars and stirrups	0.006
5.00 mm steel bars	Foundation steel	0.124
10.00 mm steel bars	Foundation steel	0.456

Table 2. Quantity of transport (Authors, 2024).

Specification of use	**Type of fuel**	**Travelled distance (km)**	**Load weight (t)**	**Vehicle tare (t)**	**Total weight (t)**	**Transport description**
Steel delivery truck – with load	Diesel oil	3.500	0.586	4.280	4.866	Light Truck
Steel delivery truck – unladen	Diesel oil	3.500	-	4.280	4.280	Light Truck
Concrete mixer trucks – with load	Diesel oil	105.000	7.931	6.300	14.231	Medium Truck
Concrete mixer trucks – unladen	Diesel oil	105.000	-	6.300	6.300	Light Truck
Pump truck	Diesel oil	24.400	-	12.900	12.900	Medium Truck
Drill trailer / warehouse – work - warehouse	Diesel oil	5.200	16.000	13.200	29.200	Semi-heavy truck
Dump trucks - with load / construction site - landfill	Diesel oil	127.600	12.000	10.900	22.900	Semi-heavy truck
Dump trucks - unladen / landfill - construction site	Diesel oil	127.600	-	10.900	10.900	Medium Truck
Dump trucks / warehouse - construction site - warehouse	Diesel oil	20.800	-	11.000	11.000	Medium Truck
Backhoe loader / warehouse - construction site - warehouse	Diesel oil	5.200	7.200	13.200	20.400	Semi-heavy truck

Table 3. Quantity of equipment (Authors, 2024; ¹ Mazzutti, 2023).

Equipment description	**Type of fuel**	**Specification of use**	**Fuel consumption (L/h) ¹**	**Time of use (h)**
Continuous flight auger drill	Diesel oil	Excavation and concreting	41.336	5.824
Pump truck	Diesel oil	Concreting	76.607	3.055
Backhoe	Diesel oil	Soil removal	8.065	12.000

2.3 Calculation tool

The Carbon Emission Calculator for Foundation Works developed by Mazzutti (2023) was used for the calculations. To evaluate the carbon dioxide emissions of the materials, the calculator considers equation 1 according to Zhang and Wang (2016), where E_M is the emission of CO_2 incorporated into materials (i) in tCO_2, where n represents the number of types of materials, mi is the quantity of material of type i in tons, and $EF_{mat,i}$ is the carbon emission (tCO_2/t) of the material of type i.

$$E_M = \sum_{i=1}^{n} \left(m_i \times EF_{mat,i}\right) \tag{1}$$

Carbon dioxide emissions due to transport are calculated using equation 2, according to Sandanayake *et al.* (2017), where E_T is the CO_2 emission of fuel type (j) in tCO_2, $EF_{trans,j}$ is the carbon emission factor for energy type (j) in tCO_2/L, ek is the energy consumption of vehicle k in (L/t.km), d_k is the distance traveled in km and w_k is the total weight of vehicle k in tons.

$$E_T = EF_{trans,j} \times e_k \times d_k \times w_k \tag{2}$$

Carbon dioxide emissions from equipment use (E_{EQ}) are expressed in tCO_2, according to equation 3, where, according to Luo, Sandanayake and Zhang (2019), $EF_{eq,k}$ is the carbon emission factor of equipment k in tCO_2/L, f_k is energy consumption in L/h and h_k is the use of equipment k in hours.

$$E_{EQ} = EF_{eq,k} \times f_k \times h_k \tag{3}$$

2.4 Emission factors

The calculator provides emission factors, so we determined the use of two scenarios considering the most current factors and in line with the characteristics of the materials and fuels used on site, one national (1) and one international (2).

Scenario 1 considered Vieira *et al.* (2022) for concrete with an EF of 0.081250 tCO_2/t, Costa (2012) for steel (1.845200 tCO_2/t) and the Brazilian GHG Protocol Program for fuels (0.002603 tCO_2/L for transport and 0.002630 tCO_2/L for equipment). For scenario 2, Hammond and Jones (2011) used concrete, steel bars and wires with values of 0.112000 tCO_2/t, 2.590000 tCO_2/t, 2.830000 tCO_2/t, respectively. For mobile and stationary combustion, the United States Environmental Protection Agency (2023) used a value of 0.002697 tCO_2/L.

2.5 Neutralization

For the carbon neutralization analysis, the calculator uses the tree planting technique. To quantify the number of plants needed, equation 4 is used, according to Azevedo and Quintino (2010).

$$N = \left[\frac{E_t}{F_t} \times 1{,}2\right] \tag{4}$$

Where N is the number of trees to be planted, E_t is the total CO_2 emission estimated in the emission calculation (tCO_2), F_t is the carbon fixation factor in biomass at the planting site (tCO_2/tree/year) and 1.2 is the compensation factor for possible seedling losses. Mazzutti (2023) uses a carbon fixation factor of 0.220 tCO_2/tree/50 years, which was found by Oliveira *et al.* (2013) and considering a period of 50 years when a building is designed to have a minimum useful life of this period (NBR 15575-1, 2024).

Santos *et al.* (2015), cites that the number of trees/ha should be equal to 1,667, since the traditional planting of tree species for the recovery of degraded areas in the Atlantic Forest Biome, which extends over part of Rio Grande do Sul, is carried out at a spacing of 3 x 2 meters.

2.6 Interpretation and discussion of results

After obtaining the results of the emissions and neutralization of the foundation work, the data was compiled, analyzed, compared with the results of other authors, and discussed, identifying the amount of carbon dioxide emitted in each scenario, the participation of each category in the total emission and the number of trees needed for neutralization.

3 RESULTS

3.1 Emissions inventory

The quantities collected in the methodology were allocated to the calculator and the emissions of each item were determined, which are presented in Table 4. In this, for combination 1 for materials, transport, and equipment, 15.793 tCO_2, 0.553 tCO_2, 1.504 tCO_2 were found, for combination 2, 20.173 tCO_2, 0.572 tCO_2, 1.541 tCO_2 were identified, resulting in a total emission of 17.850 tCO_2 and 22.286 tCO_2, correspondingly.

Table 4. Emissions for each component (Authors, 2024).

Item	**Emission in scenario 1 (tCO_2)**	**Emission in scenario 1 (tCO_2)**
Concrete 25 MPa	14.712	18.654
1.25 mm annealed wire	0.011	0.017
5.00 mm steel bars	0.229	0.321
10.00 mm steel bars	0.841	1.181
Steel delivery truck – with load	0.002	0.002
Steel delivery truck – unladen	0.002	0.002
Concrete mixer trucks – with load	0.135	0.140
Concrete mixer trucks – unladen	0.077	0.080
Pump truck	0.028	0.029
Drill trailer / warehouse – work - warehouse	0.008	0.008
Dump trucks - with load / construction site - landfill	0.149	0.154
Dump trucks - unladen / landfill - construction site	0.126	0.130
Dump trucks / warehouse - construction site - warehouse	0.021	0.021
Backhoe loader / warehouse - construction site - warehouse	0.005	0.006
Continuous flight auger drill	0.633	0.649
Pump truck	0.616	0.631
Backhoe	0.255	0.261

With regard to materials, concrete stood out as the main emitter, contributing approximately 93% of emissions. As for transport, dump trucks were the biggest emitters due to the 11 trips required for the journey construction site – landfill - construction site, which accounted for around 50% of emissions. Regarding equipment, the continuous propeller drill was identified as the largest source of emissions, contributing around 42% of the total in both combinations.

The contributions of the categories of materials, transport and equipment to total emissions were 88.48%, 3.10%, 8.43% in scenario 1 and 90.52%, 2.57%, 6.91% in scenario 2, with averages of 89.50%, 2.83%, 7.67%, respectively. Mazzutti (2023) studied emissions from a project involving excavated piles using the same emission factors references, finding percentage shares of 87.41%, 4.77% and 7.82% at the national level and 89.61%, 3.96% and 6.43% internationally for materials, which are aligned with the values of this research.

Sandanayake *et al.* (2017), an international study, found values of 72.10%, 13.40% and 14.40% for a pile construction project; Luo, Sandanayake and Zhang (2019) identified 67.90%, 17.35% and 14.75% for in-situ piles and 74.62%, 18.87% and 6.50% for precast piles. These differences identified by the authors were mainly due to the variation in the type and quantity of materials used, and the use of emission factors covering all GHGs, which would theoretically have higher values than those used in this study, due to the consideration of a greater variety of gases. However, it was not possible to access the authors' databases to make comparisons, due to their private nature. In addition, the variations in the types of vehicles and equipment used, energy consumptions, energy sources and distances traveled may also have contributed to the difference observed.

3.2 Neutralizing emissions

Table 5 shows the scenarios for neutralizing the CO_2 emitted. The percentage difference between the lowest and highest number of trees required was 24.49%, equivalent to 24 trees. Mazzutti (2023) investigated the emissions from a foundation project using the same references of emission factors adopted in this research. For Scenarios 1 and 2, the author found 0.522 and 0.651 tree/m² of foundation, respectively, as her study identified 0.096 and 0.119 tCO_2/m^2 of foundation, which were higher than this research, which identified 0.026 and 0.032 tCO_2/m^2 of foundation, correspondingly.

Table 5. Neutralization analyses (Authors, 2024).

Scenarios	**Number of trees (units)**	**Planting area (ha)**	**Tree / m² of foundation**
Scenario 1	98	0.059	0.142
Scenario 2	122	0.073	0.177

4 CONCLUSIONS

Civil construction is a sector that has a major influence on society, but it is also responsible for a significant environmental impact, contributing a considerable share of global greenhouse gas emissions and final energy use. The case study revealed two viable scenarios for analyzing the foundation work in the emissions calculator: one based on national emission factors, resulting in an emission of 17.850 tCO_2, and the other using international factors, with an emission of 22.286 tCO_2. Materials were the components that contributed most to emissions, followed by the use of equipment and transportation, with an average of 89.50%, 7.67% and 2.83%, respectively.

To neutralize the emissions by planting trees for a period of 50 years, it was identified that for the highest emission 122 trees would be needed, which would occupy an area of 0.073 ha, resulting in a need for 0.177 tree/m² of foundation. The lowest emission would require 98 trees and a planting area of 0.059 ha, resulting in 0.142 tree/m² of foundation. The calculations and results presented provide valuable input for engineers to understand one of the possible techniques for carbon neutralization, promoting a reduction in the environmental impact associated with construction activities, contributing to the evolution of engineering that is more aligned with the principles of sustainability.

Decarbonization is a global challenge that requires the adoption of sustainable solutions in construction. Reducing carbon dioxide emissions is a priority to ensure a more resilient future for future generations. In this sense, this study contributes to a civil construction aligned with the reduction of environmental impacts, the Environmental, Social and Governance Agenda of companies, the United Nations Sustainable Development

Goals and the transition to a low-carbon economy.

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