Estimation of greenhouse gas emissions in civil construction for a modular construction on the campus of the Federal University of Rio de Janeiro, Brazil

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Abstract. The civil construction industry is recognized as one of the activities with the greatest environmental impact on the planet, in addition to being responsible for about 10% to 20% of emissions in the extraction of raw materials and manufacture of products for this segment. The main objective of this work was to estimate greenhouse gas emissions for the construction of an administrative building at the Federal University of Rio de Janeiro, Brazil, using the modular constructive method. The methodology used to inventory emissions was structured in the Brazilian greenhouse gas protocol program, the method most used worldwide by companies and governments for conducting greenhouse gas inventories. The research was also developed by simulating its construction by the “Conventional” method using construction materials, a source of great relevance in the literature. Based on the results of the inventory, the total greenhouse gas emission was estimated at 462.90 tCO₂e for the construction of the project, with a built area of 620.03 m², which resulted in the emission of 0.75 tCO₂e/m² of built area. Comparatively, this constructive method presented 22.12% less emissions when compared to the conventional method. This result allows, as a mitigation action, the possibility of proposing the implementation of new technologies and constructive methods that propitiate the reduction of greenhouse gas emissions.

1. Introduction
Climate change has been pointed out, today, as one of the greatest challenges of humanity [1]. According to the United Nations Environment Program, we are experiencing a scenario of climatic urgencies and working on these issues means guaranteeing the quality of life in our society [2]. Thus, the issue of climate change is no longer just a scientific curiosity and one of many environmental concerns and has become the main environmental issue of our time and the biggest challenge for environmental regulators. As the causes of climate change are related to the increase in those obtained from greenhouse gases (GHG), the consumption of fossil fossils, industrial production, deforestation and forest degradation [3]. In this context, the scientific community has been focusing heavily on the study of related themes, categorized, for example, as conditions of the future climate, to project the impacts produced, to think of the best solutions for the reduction of the categories. Thus, as the climate issue advances in world politics, legal and marketing requirements increase, and some companies are already preparing for the trend of Brazilian laws that are increasingly restrictive in relation to GHG information [4].

Ranked among one of the main current emerging economies, Brazil faces the challenge of establishing low-carbon economic development standards, and the realization of the GHG incentive is
the initial action of entrepreneurs who want to contribute to the issue of climate change in order to minimize the negative effects. Several states and municipalities already have enacted laws to regulate climate change policy, and all these laws and bills include the realization of a GHG Inventory to determine goals and objectives for limiting information. By taking inventory of GHG, an organization obtains to identify its most relevant sources and to adopt capable measures to reduce or compensate its impacts. According to data from the United Nations, the Civil Construction Industry is recognized as one of the activities with the greatest environmental impact on the planet.

According to data from the United Nations, the Civil Construction Industry is recognized as one of the activities with the greatest environmental impact on the planet. This activity extracts 30% of materials from the natural environment, generates 25% of solid waste, consumes 40% of all energy and 25% of water, and occupies 12% of the land, therefore, the civil construction sector also has an important role in reduction of GHG emissions in the atmosphere and can contribute significantly. From appropriate inventories, it is possible to implement objective actions and analyze new solutions for projects, in the case of civil constructions, from the definition of the architectural party, to the complementary projects, as well as the inclusion of new technologies and construction methods, in order to promote the reduction of emissions [5]

2. Methodology
To prepare the inventory, the structuring, specifications, and technical notes of the GHG protocol tool (Brazilian GHG Protocol program) [6] was used, and the respective emission factors were made available and based on publications such as Intergovernmental Panel on Climate Change (IPCC), Department for Environment, Food and rural Affairs (DEFRA), United States Environmental Protection Agency (US EPA), among others, to verify and validate the applicability of the proposed method through its use in this case study. The inventory was also developed according to the norms and principles of the Brazilian GHG Protocol program. In addition to the methodology, its conceptual steps were also followed, which include: definition of the organizational and operational limits of the inventory; selection of the calculation methodology and emission factors; the collection and compilation of data from activities that emit GHGs; the calculation of emissions; and the preparation and consolidation of the inventory.

2.1. Organizational limits
Engineering and Construction activities, unlike most industries, emission activities take place in facilities that have limited activity time and correspond to the works contracts. Therefore, for the organizational limits, the modular construction for the administrative building of the national museum was considered, which is part of the implementation project of the campus annex to the national museum of the Federal University of Rio de Janeiro, located in the State of Rio de Janeiro, southeastern region of the Brazil and located according to geographic coordinates (22°54'29.1"S 43°13'40.3"W).

2.1.1. Construction description: administrative building of the national museum. The building is basically made up of the union of 34 metallic habitable modules, separated into four groups by a corridor and a central patio, in a total area of 620.03 m². The modules consist of chassis, pillars, roof, trapezoidal steel plate for external sealing (facades) and roof, as shown in the three-dimensional (3D) isometric view of Figure 1. Among the main characteristics and advantages of the modular construction system, we can mention: high production speed (off-site); shorter lead time; flexibility; reuse and portability; eco-efficiency and sustainability.

Study by GVR-Grand View Research (2019) indicate that the global modular construction market was valued in the year 2018 at $112.3 billion and held the largest share of the construction segment (64.4%) and is expected to show a compound annual growth rate (CAGR) of 6.5% for the period 2019 - 2025, reaching approximately $174.5 billion [7].
2.2. Operational limits

The definition of operational limits corresponds to the identification of sources of GHG emissions that were effectively quantified and included in the inventory. The emission sources were classified as direct or indirect emissions and defined, according to the methodology applied, in three scopes (scope 1, scope 2, and scope 3), defined below and which included: the consumption of fossil fuels used in own- or third-party equipment and transportation; the acquisition of electricity; the generation and disposal of solid waste and the consumption of construction materials used in the construction site and the fossil fuels used in the respective transportation.

2.2.1. Scope 1 (direct greenhouse gases emissions). Includes emissions through fuel consumption from sources owned or controlled by the company and includes own or leased equipment to operate under its management. In this category were considered, therefore, the fixed and mobile equipment that operated at the construction site and transport, such as owned or leased vehicles.

2.2.2. Scope 2 (indirect greenhouse gases emissions from purchased energy). Considers emissions from the generation of electricity or thermal energy acquired by the company and used in its activities. In this scope, all monthly electricity consumption (KWh) purchased to meet the demand of the construction site (lighting and operation of machinery and equipment) was considered.

2.2.3. Scope 3 (other indirect emissions). Are a consequence of the company's activities but occur in sources that are not owned or controlled by the company; although the GHG protocol methodology indicates that this scope is optional or flexible, according to the literature and the methodological guide by “Sindicato da Indústria da Construção Civil do Estado de São Paulo (SindusCon-SP)” [8], the peculiarity of the civil construction sector indicates that scope 3 comprises an extremely significant portion of a construction site's GHG emissions, i.e., it is where the largest groups of emission sources are found.

2.3. Reference period and base year of the inventory

The data for the present inventory were determined for the period of construction of the building, established by contract and in line with the executive work schedule that covered the year 2020. According to the General Standards, the Inventory must be determined permanently and with periodicity annual, or more frequent if the company so wishes, however, for inventories of works, the methodological guide SindusCon-SP [8] recommends that it be calculated throughout the executive period of the work, being the object of a closing at the end of it, totaling the GHG emissions of the work from its beginning until delivery for use.
2.4. **Emission factors**

Emission factors are coefficients that, combined with activity data, allow the quantification of GHG emissions by a certain unit of the activity, and that if adopted in a standardized way would provide an increase in the level of precision of calculations and estimates [9]. Given the recommended principles, the emission factors used in the calculation tool were based on the activities recognized and evaluated in the inventory and their determination was given by the guides and guidelines for emission inventories of the IPCC and the Brazilian GHG protocol program. In this context, we highlight the IPCC guidelines [10], the United Nation (UN) scientific arm for climate change, which maintains and publishes a large bank of emission factors, internationally recognized and used in inventories, in addition to technical references. In Brazil, the PBGHG protocol, through its tool, also provides, by default, a series of emission factors for use in the country.

Consolidated the survey of activity data and respective emission factors, calculations were established by emitting sources and separated by Scopes. This calculation methodology varied between the various equations and parameters, preferably according to the national reality, in order to assess the evolution of the management of GHG emissions over time and through an index of intensity of emissions.

3. **Results and discussions**

In this phase, in accordance and following the final conceptual and methodological steps of the GHG Protocol, proposed for carrying out GHG emission inventories, the emission results were compiled by Scope and presented as follows and according to the specificity of each.

3.1. **Scope 1: direct emissions**

This scope includes stationary and mobile sources owned or controlled by the construction company, and emissions from the burning of fossil fuels originated within the defined organizational limits were covered. The consumption of fuels by stationary and mobile sources, used in the course of the work, resulted in a total emission of 5.647 tCO$_2$e, referring to the consumption of diesel oil and gasoline, as presented in Table 1.

| Equipment        | Fuel  | Consumption (L) | Total tCO$_2$e |
|------------------|-------|-----------------|----------------|
| Stationary sources | Diesel  | 124.00          | 0.324          |
|                  | Gasoline | 563.00          | 1.272          |
|                  | Emission tCO$_2$e | 1.595          |                |
| Mobile fonts     | Diesel  | 1101.40         | 2.916          |
|                  | Gasoline | 491.85          | 1.136          |
|                  | Emission tCO$_2$e | 4.052          |                |
|                  | Total emission tCO$_2$e | 5.647          |                |

3.2. **Scope 2: indirect greenhouse gases emissions from purchased energy**

From the electricity consumption data, made available by the company, and under the approach of organizational limits and operational control, the total emissions for the established inventory period were calculated. The monthly emission factors of the National Interconnected System (SIN) [11] were used, listed, and applied to obtain the results, as shown in Table 2. Emissions for scope 2 resulted in a total emission of 0.123 tCO$_2$e, for the executive construction period between March and October 2020 and essentially in the construction and operational phases of the construction site.

The variations observed in the monthly emission factors are due to the variation in the participation of thermoelectric plants in the Brazilian energy matrix to serve the system in hydrologically unfavorable periods (seasonality) or even to complement generation oscillations, load, or even operational restrictions.
Table 2. Emissions generated by the consumption of electricity (tCO$_2$e).

| Year | Month | KWh | Factor (tCO$_2$/MWh) | Emission (tCO$_2$) |
|------|-------|-----|----------------------|-------------------|
| 2020 | March | 100 | 0.0384               | 0.0038            |
|      | April | 583 | 0.0296               | 0.0173            |
|      | May   | 211 | 0.0358               | 0.0076            |
|      | June  | 330 | 0.0491               | 0.0162            |
|      | July  | 586 | 0.0400               | 0.0234            |
|      | August| 586 | 0.0414               | 0.0243            |
|      | September | 429 | 0.0329               | 0.0141            |
|      | October| 168 | 0.0961               | 0.0161            |
|      | Total |     |                      | 0.1230            |

Table 3. Total scope 3 emissions.

| Emission sources       | tCO$_2$e | %  |
|------------------------|----------|----|
| By using fuels         | 6.058    | 1.33|
| Waste generation       | 48.610   | 10.63|
| Use of building materials | 402.460  | 88.04|
| Total emissions        | 457.128  | 100.00|

3.3. Scope 3: other indirect emissions

Objectively, and through the results obtained that make up scope 3 (Table 3), it can be seen, in relation to emission sources, that the use of construction materials applied during the execution of the work has the greatest representativeness and importance within the scope, with a contribution of 402.46 tCO$_2$e, which represents about 88.04% of the emissions of a total of 457.128 tCO$_2$e.

One of the specific objectives of this study was to establish a comparative relationship of emissions between the modular and the conventional building methods, especially for the use of construction materials and between the most relevant stages, which differ either in their quantity or in the type of materials or inputs that make up certain services. The calculated and totalized emissions per activity, in both conditions, reached the values of 402.46 tCO$_2$e and 491.50 tCO$_2$e, respectively. This difference represents a percentage of 22.12% in favor of the modular construction method.

The study and the results obtained for the GHG emissions show that the modular construction methodology, in the different construction stages, and ordered according to their relevance, has its greatest contributions in the services of the infra and superstructure stages (247.36 tCO$_2$e); metallic structure (housing modules) with 42.08 tCO$_2$e and hydro-sanitary installations (30.65 tCO$_2$e). These three stages of services correspond to 79.54% of the total emissions accounted. This result highlights the prominence and prevalence of the most used services and inputs in the respective work stages and main link in the construction chain, such as concrete (steel and cement); metallic structure (steel) and installations (plastic materials/PVC).

In comparative and total emission terms, despite the modular construction method reaching a lower value, compared to conventional construction, some services had higher emission levels, as represented by the graph in Figure 2. This fact can be explained by associating the respective services and respective construction materials to the emission factors and the relevance of each one in view of the proposed construction methodology for the construction.

For the Infra and superstructure service, the largest amount of reinforced concrete (cement and steel) used in the conventional construction version prevailed, in contrast to the steel structure by the modular method. The internal partitions and the external closings, the emissions resulting from the use of ceramic brick blocks prevailed, in relation to the drywall and metallic sheet partitions of the modular construction, which also determines a greater use of mortar and consequently more cement.
In the emissions originated by the execution of the Roof, in modular construction, the predominance of the use of the material (steel) is observed, both in the metallic structure used for the structuring of the roof, as a component of the isothermal metallic tile (faces), when compared to conventional, which uses structure in wood and tile in fiber cement, and which resulted in a lower amount of emissions. For the painting, the emissions varied only according to the quantity of the different areas covered.

![Figure 2. Comparative graph of emissions between construction methods according to their activities.](image)

3.4. Totalization of emissions and consolidation of the inventory

The consolidated inventory, for the construction under study, presented a total emission of 462.90 tCO₂ₑ, being 5.647 tCO₂ₑ for scope 1; 0.123 tCO₂ₑ for scope 2 and 457.128 tCO₂ₑ for scope 3, as observed through the graphical representation of Figure 3.

The results obtained show that 98.75% of the total emissions correspond to Scope 3. Therefore, this scope concentrates the largest groups of emission sources, which result from the manufacturing process, in all its phases, of construction materials and derived products, mainly using steel and cement.

![Figure 3. Emissions in tCO₂ₑ by scope.](image)
4. Conclusions
In the constructive aspect and in terms of industrialization, the built building can be considered an open cycle, as its components and elements originated from a common market and are compatible with each other and classified as modular hybrid construction. In a comparative relation, it was estimated that the modular construction method, presented about 22% less emissions from construction materials than the conventional method, signaling with this, that the previous choice of certain components and elements that integrate the construction, are extremely important in the context of total emission reduction by this source and as a significant mitigating action.

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