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ANALYSIS OF CO_2 EMISSIONS BETWEEN CONSTRUCTION SYSTEMS: LIGHT STEEL FRAME AND CONVENTIONAL MASONRY

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Abstract

Since the emission of greenhouse gases is an important environment issue, this paper presents an analysis of CO_2 emissions between two different building methodologies: conventional masonry and light steel frame. To this end, a 70m² building project used in Social Brazilian Housing Programs (SBHP) built according to both methods was analyzed. In addition to that, the quantitative materials used were determined, according to the building services (infrastructure, superstructure, closing and cladding, roof and floor) and afterwards, were multiplied by conversion factors. These conversion factors allow estimating the CO_2 emission from the manufacturing process of the material up to its application, which made it possible to determine the total CO_2 emission for both building methodologies. Furthermore, a cost analysis was carried out in order to interpret economic issues in both methods. The results showed that infrastructure and superstructure are the main services responsible for CO_2 emission in both constructive methodologies, due to the high consumption of concrete, steel, coarse aggregates and wood, where differences of almost 90% were identified. Moreover, although the conventional masonry method presented low global cost in comparison with light steel frame, this method emits more than 102% of CO_2 in relation to the latter. Therefore, from an environmental point of view, builders should consider this issue when choosing a construction system.

Key words: civil construction, CO_2, greenhouse gases, light steel frame, masonry

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1. Introduction

Cities, as human spaces, meet the basic and immediate needs of their individuals. However, for a long time the architectural and engineering solutions were not concerned about the permanent changes produced in the environment due to civil construction activities. Consequently, comfort at any cost was the main concern of most architectural projects. It was only at the end of the twentieth century that the urban environment became the main interest. New concepts and concerns were synthesized by the movement known as "sustainable development", due to which, environmental issues received increased attention because of the impacts generated by civil construction activities (Akhtar and Sarmah, 2018; Hansen, 2008; Xiao, 2018).

Civil construction industry consumes almost 75% of the natural resources such as limestone, clay, wood, sand, gravel, minerals and others for its activities, and it is responsible for large carbon dioxide (CO_2) emissions, strongly contributing for global warming. This is exemplified by the fact that the civil construction sector emits 7 to 10% of the total CO_2 worldwide only for cement production (Andrade et al., 2018; Hansen, 2008; Singh and Singh, 2016). About

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this issue, Huang et al. (2018) analyzed the CO_2 emission of the global construction sector pointing that 23% of the total global emissions is related to this sector, corresponding to more than 5.7 billion tons per year. Another important point observed by the authors is that, while 60% of these emissions are from emerging countries, China is the main global contributor. In fact, Chen et al. (2017) corroborated this observation and pointed that CO_2 emission between 1996 and 2011 was exponentially increased in China due to its economic growth.

In order to harmonize economic development and environmental preservation, it is necessary to reduce the impacts caused by the civil construction industry to the environment. On this point, encouraging projects and building methodologies that ensure the rational use of natural resources, the reduction of CO_2 emissions and waste generation are the key points to environmental preservation. (Koyano et al., 2019; Thomas et al., 2018; Wang et al., 2018; Wang et al., 2019). In this context, one of the main innovations presented recently in literature deals with the adoption of lean techniques for industrial construction, as presented by Heravi et al. (2019) and Heravi et al. (2020), since industrial construction has been presented as a suitable way to minimize environmental impacts of construction process. In these works, the authors analyzed the production and erection processes of pre-fabricated steel frame in an eight-story residential building project in Tehran, Iran. The main results show that the total time and cost of project improved 43% and 17% respectively, whereas the energy consumption and CO_2 emissions were reduced by 9.2% and 4.4% respectively due to the application of lean techniques in the industrial construction process.

Still from this perspective, the selection of materials and construction techniques are the first step in the process of adopting new postures aiming environmental preservation. Several studies have been presented in literatures in order to estimate the CO_2 emission according to the materials and/or the constructive methodology used. One of the main goals of these studies is to stimulate the adoption of tools that can help builders to choose a construction method that results in less impact to the environment, mainly when social housing programs are analyzed, since a significant number of houses are built using public funds. For that matter, in Brazil, the housing deficit is approximately 8 million according to the Brazilian Institute of Geography and Statistics (IBGE, 2019), showing not only the need for construction, but also for methods that supply this demand considering the environment preservation.

Literature studies are dedicated to estimate CO_2 emission according to the materials and construction type or methodology, estimating the CO_2 emission by applying conversion factors that multiply the materials consumption. For that matter, Jeong et al. (2012) estimated that, on average, the amount of CO_2 emission of an apartment built with common materials as concrete, wood, steel and masonry is approximately 569.5 kg CO_2/m^2 in Korea, where the main factors responsible for this value are concrete and steel. Seo and Kim (2013) analyzed the CO_2 emission of materials used in road construction (roads, bridges and tunnels). The authors observed that bridge constructions emit more CO_2 than tunnels and roads (120.1 tons of CO_2 per meter, whereas tunnels and roads emitted 29.6 and 7.5 tons of CO_2 per meter respectively). Mao et al. (2013) and Ji et al. (2018) presented a quantitative model in order to determine CO_2 emission between prefabricated and conventional construction methods considering transportation of materials, equipment operation, prefabricated components and waste generation. The results showed that prefabrication methods produce less CO_2 than conventional methods during the process since this is a more rational method of producing a civil structure. Cao et al. (2015) compared prefabrication technology and cast-in-situ technology of residential projects. The authors observed that prefabrication method presents advantages from the perspective of environmental impact as a reduction of 35.85% in resource depletion, corroborating the model observations from Mao et al. (2013) and Ji et al. (2018). Choi et al. (2016) investigated the CO_2 emission of steel reinforced concrete composites. The authors showed that, from a perspective of CO_2 reduction emission, increasing the cross-sectional area of steel shape is more advantageous than increasing concrete cross-section, since concrete is one of the main emitters of CO_2, due to its high consumption. In fact, Akan et al. (2017) pointed out that concrete production emits significant amounts of CO_2 contributing to global warming, since concrete consumes significant cement amounts, whose production process contributes to large CO_2 emissions.

The aforementioned information lead to the observation that studies deal with CO_2 emission from the perspective of materials and/or construction methodologies. Nonetheless, most of the studies compare conventional buildings whose structural systems are essentially composed of reinforced concrete columns, beams and slabs, pre-fabricated or cast-in-situ, with ceramic brick walls for closing. On this point, few are the studies that consider a comparison between different structural systems for the same building project, mainly when the application is related to social housing programs. Furthermore, when it comes to a significant number of houses with the same characteristics, the construction process has been changing in Brazil, since production optimization and profit maximization have been the biggest concern of builders when choosing a constructive methodology, regardless of the construction impacts on the environment. From this perspective, this paper aims to contribute to builders' decision-making, regarding the selection of constructive methods for social housing programs that least affect the environment.

For that reason, CO_2 emission analyses were carried out considering a housing project for a Brazilian social housing program, called "Easy

Home", comparing two different constructive techniques: conventional construction with masonry and light steel frame. These constructive methodologies were selected because the former is the current standard construction method used for housing building nowadays in Brazil, and the latter is a technique emerging in the Brazilian construction market, mainly when a significant number of houses with the same characteristics are built, as in social housing programs.

Throughout this analysis, the specifications of Costa (2012) were observed. Such specifications are based on the GHG Protocol – Corporate Accounting and Reporting Standards (2015), GHG Protocol – Corporate Value Chain (Scope 3) Accounting and Reporting Standard (2015) and the Brazilian Standard ABNT NBR ISO 14.062-1 (2007), allowing researchers to identify what building stages are responsible for high CO_2 emission through the analysis of the materials. Costa (2012) methodology was chosen since it considers Brazilian construction characteristic as materials, labor costs and operational issues for determination of conversion factors. On this point, the conversion factors used in this methodology can express Brazilian market and can be applied for social housing programs.

At this point, although Brazil presents significant sources of raw materials for construction industry in relation to other countries, some Brazilian construction characteristics should be pointed. According to the Sustainable Council for Sustainable Construction (2015) building materials chain in Brazil consumes almost half of the raw materials extracted from nature, consequently the sector uses materials found in abundance and at low cost.

In this sense, wood, cement, sand and gravel, heavy clay and steel represent the most common materials used in Brazilian market, justifying the adoption of conventional masonry construction methods using mainly concrete, mortar, wood (molds and structures), ceramic bricks and tiles as the main constructive methodology. Souza and Pinho (2016) highlighted the use of conventional masonry as the main constructive system adopted due to the productive culture in Brazil and broad knowledge of its technique allied to the scarcity of industrial labor for civil construction, thus, the first choice of builders is for conventional masonry methods.

Furthermore, the Sustainable Council for Sustainable Construction (2015) and Monteiro et al. (2016) pointed that part of the heavy consumption of materials and waste generation in Brazilian construction (approximately ¼ of the total industrial waste generated in Brazil come from civil construction) are associated with loss of materials in construction sites. Nonetheless, fiscal policy has overly delayed the industrialization of Brazilian construction, reducing sector productivity and increased losses, leading to significantly low performance buildings and high environmental impacts, demonstrating the need to seek new constructive methodologies.

2. Experimental

This experimental program is based on a quantitative and qualitative study of the environmental impacts resulting from the life cycle of the materials used in two construction systems: light steel frame and conventional masonry. From this perspective, it is possible to evaluate the real role of each system in relation to its implication as transformer agent of the human environment. It is believed that the results of this research can raise important issues regarding the impact of civil construction methodologies in the urban environment.

In order to carry out the comparative study, the standard projects from the housing program known as "Easy Home" in Cascavel – a city in the state of Paraná, Brazil - were selected to perform the evaluations of both systems. Fig. 1a presents the standard project for construction in light steel frame or conventional masonry, both presenting the same area and residence rooms and Fig. 1b presents an image with houses built in the "Easy Home" program. One of the main differences between the methods is that light steel frame uses internal and external cementitious boards for building the walls, whereas conventional masonry uses ceramic bricks (Souza, 2017).The "Easy Home" program was created as a partnership between the Class Entities (Regional Council of Engineering and Agronomy - CREA) and the Municipal Government, aiming at the construction of popular housing with up to 70 m² for families with up to three minimum wages (approximately U$$ 740 in 2019). This social program was established in 1989 and it is working in 90% of the cities of Paraná, Brazil, promoting the integration between Class Entities, Municipal Government and the Society. Up to 2019 more than 10 million square meters (143 thousand houses) were built assisting more than 180 thousand families in this social program since 1989 (CREA, 2020).

The projects analyzed are basically composed of three bedrooms, a living room, a kitchen and a bathroom executed with conventional masonry or light steel frame. The conventional masonry presents a reinforced concrete structure (slab, beams and pillars) and ceramic bricks for wall construction, whereas light steel frame presents cementitious panels, attached by steel profiles, for the internal and external walls (Souza, 2017).

Materials were quantified in order to build the standard project using conventional masonry and light steel frame. Afterwards, the GHG emission was determined for both projects using the methodology of Costa (2012) regarding GHG Emission Budgeting. This methodology is also oriented by the IPCC - Intergovernmental Panel for Climate Change of the United Nations (IPCC, 2019) and calculates the CO_2 emissions (by conversion factors) that will be emitted by the materials considering the extraction of raw materials, its manufacturing process and transport to the construction site.

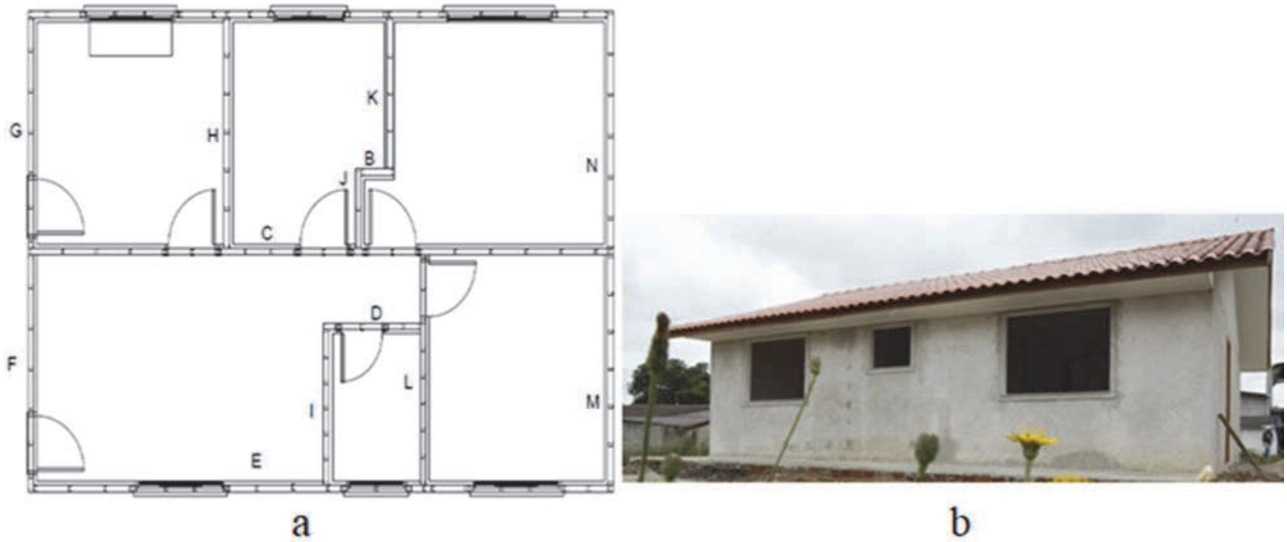


Fig. 1. (a) Standard project of a 70 m² house (Souza, 2017); (b) House unFder construction in Easy Home Program (Bortolin, 2009)

About this issue, it is important to emphasize that CO_2 emissions for hydraulic and electrical installations were not considered in this study, since they did not present significant values for the analysis performed for both methods, so in order to verify the CO_2 emission, the following services were taken into account:

- Preliminary Services: Closing works, cleanup services and construction of a warehouse for material storage;
- Infrastructure: Earthmoving and foundation execution with blocks and piles in the conventional masonry, and slab foundation in the light steel frame method;
- Superstructure: Columns, beams and slabs, in the case of conventional masonry, and application of cement board panels for light steel frame;
- Roofing: wood structure and ceramic tiles for conventional masonry and steel structure with ceramic tiles for light steel frame;
- Sealing and Cladding: Ceramic bricks in the case of conventional masonry and cement board panels for light steel frame;
- Floors: Ceramic floors and mortar on the walls for regularization and final painting.

The conversion factors used in this analysis were obtained from Costa (2012). The author developed a method for CO_2 quantification (called QE-CO_2) based on the methodology of The Intergovernmental Panel on Climate Change (IPCC, 2006). In a general way, this methodology consists of determining the amount of all materials produced and/or consumed for building (QTj, in tons) and then multiplying each one by a respective conversion factor (CF) in order to express the total CO_2 emission (in tons of CO_2) for each material. Afterwards, all the CO_2 emission is added up, demonstrating the total CO_2 emission of the building according to the materials used, as presented in Eq. 1.

It should be pointed out that Costa (2012) determined the conversion factor according to Brazilian material characteristics considering issues as raw materials extraction, transport, manufacturing of products and the characteristics of construction systems used in Brazil. For that end, Costa (2012) considered data from Brazilian Energy Balance (BEB, 2011), data from 2nd Brazilian Communication to United Nations About Climate Changes (Brazilian Ministry of Science and Technology, 2010) and Brazilian manufactures data, considering that conversion factors are dependent on the amount of materials produced and its carbon content, considering the CO_2 emissions due to raw materials extraction (E_e), transport (E_t), and manufacturing process (E_{mp}) as presented in Eq. 2. Table 1 shows the main conversion factors presented by Costa (2012) and used in this analysis.

$$Total\ CO_2\ emission = \sum_j \left[QT_j\ (in\ tons) \cdot CF\right] \quad (1)$$

$$Conversion\ Factor\ (CF) = \left(E_e + E_t + E_{mp}\right) \quad (2)$$

From this perspective, the methodology to apply these conversion factors of Table 1 consists firstly, of determining quantitatively all the material mass consumed, according to the respective service. For instance, in the superstructure stage, the total quantitative values are those of reinforcements, concrete, wood molds and timber used in the conventional masonry methodology, whereas, in the light steel frame, the quantitative values are the ones of cementitious panels and the steel structure.

After this, according to the methodology of Costa (2012), the conversion factor is used multiplying the quantitative values, allowing the determination of CO_2 emission for each service according to the construction methodology (conventional masonry or light steel frame). Furthermore, a cost analysis of both building methodologies was performed in order to compare the financial investment to build the standard project.

3. Results and discussion

Tables 2 and 3 present the detailed quantitative survey of materials used for both methodologies, whereas Table 4 presents the synthesis of the total CO_2 emission for light steel frame and conventional masonry according to the services executed. On this point, Fig. 2 presents graphically the CO_2 emission according to the building stage. The comparative between CO_2 emission between conventional masonry and light steel frame of each building stage is also presented in Table 4.

It is possible to notice in Fig. 2 and Table 4 that infrastructure and superstructure stages are the main responsible for CO_2 emission for light steel frame and conventional masonry, respectively. This fact is justified because, at these stages, the steel and concrete consumption contributes for higher CO_2 emission. Besides that, it should be pointed out that steel presents a high conversion factor (1.845) if compared to other materials as concrete (0.37), since the steel manufacturing process consumes high amounts of energy and natural resources in the process. On the other hand, concrete presents a low conversion value, but also high quantitative consumption at these stages, contributing for a significant value in the overall analysis. From this perspective, the high impact of infrastructure and superstructure in both methodologies is mainly influenced by the steel manufacturing process, which is an indirect source of CO_2 emission once it is not directly observed in the housing works, and due to high consumption of concrete at these stages, that is a direct CO_2 emission source in the building process.

Another point that should be observed is that although wood molds do not present a higher conversion factor (0.405), the quantitative consumption of these molds are high, analogous to concrete, contributing to the high CO_2 emission values presented in the infrastructure and superstructure. From this perspective, wood molds present a restrict service life or, in other words, the use of this material is limited to few reuses, consequently, in the estimative of CO_2 emission, this reuse is not considered as leading to high values of CO_2 emission.

Table 1. Conversion factors of the main materials used in the analysis according to Costa (2012)

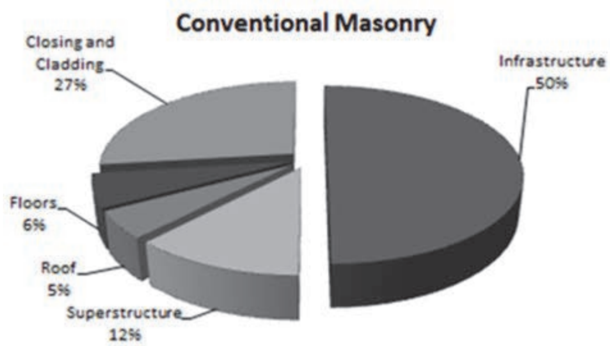
Material	*Conversion factor (tons CO_2 / tons of manufactured material)*
Coarse aggregates	0.086
Steel	1.845
Concrete	0.370
Wood molds	0.405
Cementitious board panels	0.491
Mortar	0.139
Ceramic tiles and bricks	0.111
Ceramic floors	0.187

Table 2. Quantitative of materials and CO_2 emission in Light Steel Frame

Building stage	*Description*	*Unit*	*Quant.*	*Conversion factor*	*CO_2 emission (ton.)*
Infrastructure	Gravel ballast for all foundation	ton	14.985	0.086	1.289
	Wood molds	m³	0.251	0.405	0.101
	Steel mesh (Ø 4.2 mm spaced15X15 cm)	ton	0.196	1.845	0.362
	Steel reinforcement (Ø 8 mm)	ton	0.054	1.845	0.099
	Steel reinforcement (Ø 4.2 mm) (stirrups)	ton	0.015	1.845	0.027
	Concrete fck = 20 MPa (Stake, block and beams)	m³	10.350	0.37	3.830
				Subtotal	5.709
Superstructure	Steel structure	ton	0.719	1.845	1.327
	Cementitious board panels (Thickness = 8mm) (Slab)	ton	0.162	0.491	0.079
				Subtotal	1.046
Roof	Steel structure	ton	0.280	1.845	0.517
				Subtotal	0.517
Floor	Subfloor execution	ton	3.564	0.197	0.702
				Subtotal	0.702
Closing and Cladding	Glass wool for thermal insulation	ton	0.0663	0.00135	0.0000896
	Plaster	m³	1.775	0.766	1.360
	Cementicious board (Thickness = 8mm)	ton	1.638	0.491	0.804
	Oriented strand board (Thickness = 1.0cm)	m²	2.884	0.331	0.954
				Subtotal	3.119
Total CO_2 Emission					11.452

Table 3. Quantitative of materials and CO_2 emission in conventional masonry

Building stage	***Description***	***Unit***	***Quant.***	***Conversion factor***	***CO_2 Emission (ton.)***
Infrastructure	Gravel ballast for all foundation	ton	8.990	0.086	0.773
	Wood molds	m³	1.048	0.405	0.424
	Steel mesh (Ø 4.2 mm spaced15X15 cm)	ton	0.042	1.845	0.077
	Steel reinforcement (Ø 8 mm)	ton	0.010	1.845	0.018
	Steel reinforcement (Ø 4.2 mm) (stirrups)	ton	0.141	1.845	0.260
	Concrete fck = 20 MPa (Stake, block and beams)	m³	6.070	0.370	2.246
				Subtotal	3.800
Superstructure	Wood mold (pillar)	m³	5.095	0.405	2.063
	Wood mold (beam)	m³	17.710	0.405	7.173
	Steel reinforcement (Ø 4.2 mm)	ton	0.054	1.845	0.100
	Steel reinforcement (Ø 8 mm)	ton	0.126	1.845	0.233
	Steel reinforcement (Ø 10 mm)	ton	0.029	1.845	0.054
	Concrete fck = 15 MPa (pillar and beam)	m³	2.080	0.347	0.722
	Timbering	m³	0.673	0.409	0.275
	Concrete fck = 15 MPa (lintels)	m³	0.770	0.370	0.285
				Subtotal	10.900
Roof	Wood structure	m³	1.0576	0.405	0.428
				Subtotal	0.428
Masonry	Masonry with ceramic block (Thickness = 9cm)	ton	18.582	0.111	2.062
				Subtotal	2.062
Floor	Gravel ballast	ton	18.78	0.086	1.615
	Concrete subfloor	m³	3.07	0.37	1.136
				Subtotal	2.751
Closing and Cladding	Roughcast	ton	3.108	0.139	0.432
	Plaster (Thickness = 3 cm)	ton	18.105	0.139	2.517
	Plastering	ton	2.489	0.139	0.346
				Subtotal	3.290
Total CO_2 Emission					23.221



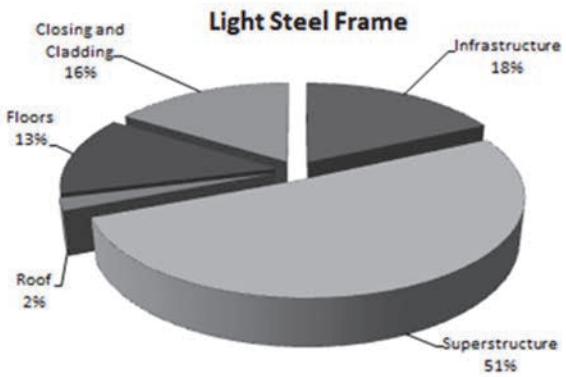


Fig. 2. Perceptual of CO_2 emission graph in the light steel frame and conventional masonry systems according to building stage

In Table 4, although infrastructure stage in the light steel frame methodology generates high CO_2 emission in relation to conventional masonry method, due to the consumption of concrete and steel used for the slab foundation for a land residence, in a general way, light steel frame is a method that emits half of the CO_2 in relation to the conventional masonry method.

This fact is justified since superstructure and floor stages generate significantly less CO_2 emission in light steel frame, showing that this constructive technique, from an environmental point of view, helps to reduce the GHG emissions in the construction industry. The details of the CO_2 emission values presented in the infrastructure and superstructure stages, for both methods, are presented in Tables 5 and 6. According to Table 5, it is clear to notice that in the infrastructure, concrete represents the highest CO_2 emissions source in comparison with other materials for both methodologies, since the consumption of this material is higher at this building stage in order to execute the slab foundation. Furthermore, comparing both methods, it is possible to notice that conventional masonry presents less CO_2 emission in relation to light steel frame (almost 15%), since the former presents less concrete and coarse aggregates consumption in comparison with the latter.

Analyzing Table 6, the difference between the methodologies is clearly shown in the superstructure. From the values, it is possible to infer that light steel frame presents almost 15% of the CO_2 emission in relation to conventional masonry, since wood molds for pillars and beams are significant contributors to CO_2 emission, being responsible for almost 90% of CO_2 emission at the superstructure stage. This analysis showed that the high consumption of wood molds is the main responsible for high CO_2 emissions during the superstructure works, even presenting a low conversion factor.

Moreover, in the superstructure, it can be seen that not conventional materials, such as steel and concrete, whose manufacturing materials process consumes high raw materials and energy amounts, are responsible for the highest CO_2 emissions, but the high consumption of wood at this stage is responsible for this result. This fact is justified since wood molds present a limited service life in this analysis, as described before considering the methodology of Costa (2012).

Fig. 3 present a synthesis of CO_2 emissions, according to the building stages, showing the percentage differences between the services. It is clear that CO_2 emissions for the superstructure, closing and cladding and floor services in the conventional masonry system are much larger than light steel frame. This fact is justified since the conventional method uses wood molds, concrete and steel bars as the predominant materials. According to this way of thinking, these main materials present high consumption or high conversion factors values according to Costa (2012), contributing for this behavior. On the other hand, infrastructure stage emits less CO_2 in the conventional method than light steel frame due to the consumption of concrete and coarse aggregates as presented in Table 6 and discussed below. When the roof is analyzed, the performance is similar for both methods, since the volume of materials for building the roof structure is proportional to its respective conversion factor. Besides, ceramic tiles are common for both methods. As for sealing and floor, a 42% and 75% variation is noticed, respectively. This behavior is justified since light steel frame uses cementitious panels, whereas, the conventional methodology uses high amounts of mortar for finishing the walls.

Table 4. Quantitative CO_2 emission summary in the light steel frame and conventional masonry systems

Service	***tons CO_2 emitted***		***% Comparative***
	Light Steel Frame	***Conventional Masonry***	
Infrastructure	5.709	3.800	+ 50.24
Superstructure	1.406	10.900	- 87.10
Roof	0.517	0.430	+ 20.23
Floors	0.702	2.750	- 74.47
Closing and Cladding	3.119	3.29	- 5.20
Masonry	-	2.060	-
Total	11.452	23.220	- 50.68

Table 5. Infrastructure detailed

Infrastructure material	***Quantity***		***ton CO_2 emitted***		***% Comparative***
	Light Steel Frame	***Conventional Masonry***	***Light Steel Frame***	***Conventional Masonry***	
Coarse aggregates	14.985 ton	8.990 ton	1.289	0.773	
Wood mold	0.251 m³	1.048 m³	0.101	0.424	
4,2 mm steel reinforcement	0.196 ton	0.042 ton	0.362	0.077	
5 mm steel reinforcement	0.054 ton	0.010 ton	0.099	0.018	
8 mm steel reinforcement	0.015 ton	0.141 ton	0.027	0.260	
Concrete fck=20 MPa	10.35 m³	6.070 m³	3.803	2.246	
Total			5.681	3.798	+ 14.95%

Another important aspect is related to CO_2 emission per square meter in both constructive systems. In this case, the CO_2 emission using light steel frame was 163.6 kg CO_2/m^2, whereas when using conventional masonry, the value was 331.73 kg CO_2/m^2 considering a building of 70m², clearly showing that light steel frame emission is lower than conventional masonry. From this point of view, Gonzales and Navarro (2006) affirm that buildings with low environment impact emit less than 200 kg CO_2/m^2. This fact shows that light steel frame is a constructive alternative for builders, when observed from the environmental perspective.

Finally, generally it was possible to notice that CO_2 emission values of the conventional system are approximately 102.76% higher than the light steel frame, mainly due to the use of materials in the superstructure stage, so although there is a significant difference in values, it is worth noticing that, not only is it important to evaluate the CO_2 emissions in a direct way during the building stages, but also the CO_2 emissions during the manufacture process of the materials should be taken into account in order to evaluate all the building process. Furthermore, considering 143 thousand houses built since 1989 in the "Easy Home" program and the total CO_2 emission presented in Table 4, it is possible to affirm that approximately 3.3 million tons of CO_2 were emitted using conventional masonry method, whereas if light steel frame method had been chosen, the total amount of released CO_2 would be approximately 1.6 million, less than half comparing to the conventional method.

As for the costs, Fig. 4 presents the building costs according to the service. For this analysis, the researchers considered the dollar quotation of October 8th, 2019 (1 Dollar = 4.09 Brazilian Real).

Another analysis that can be performed is related to carbon cost effect. For that matter, World Bank Group (2019) presents the state and trends of carbon pricing, where it is possible to notice a significant variation of carbon tax among different countries, from less than US$ 1/ton. CO_2 (Mexico, Ukraine and Poland carbon tax) to a maximum of US$ 127/ton.CO_2 (Sweden carbon tax). The same reference presents that to achieve the Paris Agreement temperature target (2015) the minimum price range needed should vary between US$ 40-80/ton.CO_2 by 2020.

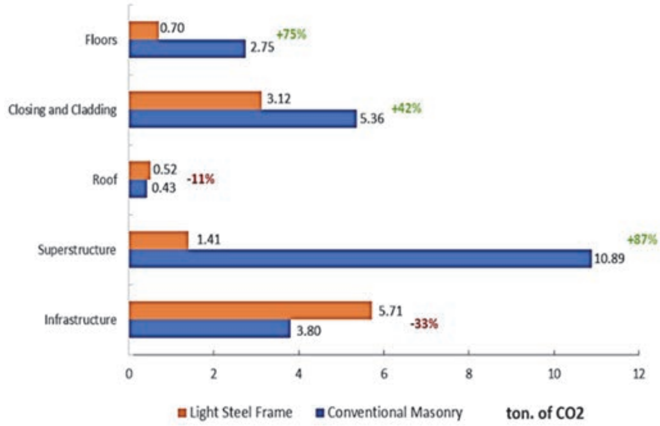


Fig. 3. Comparison of CO_2 emission according to the building stages in the light steel frame and conventional masonry systems

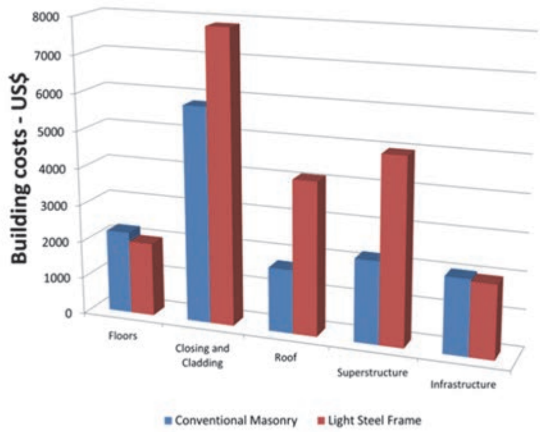


Fig. 4. Building costs according to the service

Table 6. Superstructure detailed

Superstructure material	*Quantity*		*ton CO_2 emitted*		*% Comparative*
	Light Steel Frame	*Conventional Masonry*	*Light Steel Frame*	*Conventional Masonry*	
Form - pillar	-	5.095 m³	-	2.063	
Form - beam	-	17.710 m³	-	7.173	
4.2mm steel reinforcement	-	0.054 ton	-	0.100	
8mm steel reinforcement	-	0.126 ton	-	0.233	
10 mm steel reinforcement	-	0.029 ton	-	0.054	
Concrete fck = 15MPa	-	2.080 m³	-	0.722	
Eucalyptus props	-	0.673 ton	-	0.275	
Concrete 15 MPa – Lintel and Sill	-	0.77 m³	-	0.267	
Steel Structure	719.08 kg	-	1.327	-	
Concrete Slab	0.1618 ton	-	0.079	-	
Total			1.406	10.89	- 87.09

Notwithstanding, considering the dynamic carbon price value presented in February 24, 2020 by Ember Climate (2020) of US$ 24.11/ton.CO_2 the carbon price is low in relation to the values recommended by the World Bank Group. Anyway, considering the lowest value recommended by the World Bank Group (2019) of US$ 40/ton.CO_2 and the total CO_2 emitted by light steel frame and conventional masonry presented in Table 4, it is possible to affirm that carbon cost of light steel frame is equal to US$ 458.08, whereas conventional masonry is US$ 928.80, showing a 203% difference between both methods.

Moreover, considering that the "Easy Home" program constructed approximately 143 thousand houses since 1989 with a carbon price of US$ 40/ton.CO2 (World Bank Group, 2019), if the constructive system used had been light steel frame, the total carbon price should be approximately US$ 65 million (US$ 2.1 million/year on average), whereas considering conventional masonry the total carbon price is approximately US$ 133 million (US$ 4.4 million/year on average). This fact reinforces the importance of wisely choosing a constructive method, since maximizing the carbon cost for social housing programs, especially when a significant number of houses are built, affects not only the environment but also the economic issues related to carbon.

4. Conclusions

This paper presents a qualitative and quantitative comparison of CO_2 emission between light steel frame and conventional masonry construction methods for a Brazilian social housing program. The main conclusions that can be drawn are:

- Infrastructure and superstructure are the main stages responsible for high CO_2 emissions in the conventional masonry and light steel frame respectively, where both stages correspond to more than 50% of CO_2 emission, mainly due to the materials consumption as wood, concrete and steel.
- Overall, the emission of CO_2 in the conventional masonry method is more than 100% higher than light steel frame. On this point, light steel frame can be classified as a low environment impact constructive methodology, since the CO_2 emission per square meter was less than 200 kg, showing that this method is a viable constructive system from the environmental perspective. On the other hand, it was analyzed that light steel frame presented an overall cost 50% higher in relation to conventional masonry method explaining the reason why conventional masonry method is directly chosen by builders.
- A carbon cost analysis was performed and showed that conventional masonry method cost is 200% higher than light steel frame. Furthermore, considering all houses built since 1989 in the Brazilian social housing program the estimation of carbon cost is higher than US$ 130 million.

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