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LABOUR PRODUCTIVITY AS A MEANS FOR ASSESSING ENVIRONMENTAL IMPACT IN THE CONSTRUCTION INDUSTRY

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Abstract

Managing standards and environmental laws in the construction life cycle have become essential to constructors. In general, Life Cycle Assessment (LCA) methods quantifying environmental impact factors in the construction phase do not measure the impacts caused by the workers. This research introduces labour productivity as a possible LCA input-output factor, based on CO_2 emissions and generation of sanitary wastewater. The presented methodology aims to determine the environmental impact related with labour productivity, in a simple and agile way, for application in all types and sizes of construction projects. Through the application of this methodology, worked Labour-hour connects directly to the environmental impact. The findings evidence that craft workers who directly perform tasks on construction sites might potentially generate a higher volume of wastewater (nearly more 33%) and emit 1185% more CO_2 emissions than workers who perform only administrative activities. These values point that craft workers on duty/on-site exhale more CO_2 and discharge more wastewater than at home. Even though indirect workers may have similar emission levels while working or at home, their emissions assessment is relevant for construction industry LCA analyses. Beyond this, a case study evidence that developing countries with lower productivity may cause greater environmental damage than developed countries. In order to carry out the same task in less developed countries, a higher number of craft workers is necessary, which leads to a higher number of managers, increasing the staff office needed.

Key words: environmental impact assessment, building, labour productivity, workers

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1. Introduction

Building construction over time stands out as a crucial factor for the social and economic development of civilisations (Abd Rashid and Yusoff, 2015). The environmental impacts caused by the construction industry are expressive. The building cycle begins with the pre-design/design requirements and the selection of products (materials and components) (Treloar et al., 2000). These, through construction-installation processes, are transformed, consuming energy and water. This generates waste, causing other disturbances to the environment in which they are inserted (European Commission, 2014; Soust-Verdaguer et al., 2017; Treloar et al., 2000). Subsequently, the built object continues to affect the environment directly and indirectly throughout its operation, maintenance, refurbishment and demolition (European Commission, 2014; Treloar et al., 2000). As a result, the construction industry points out as one of the sectors that most uses and exploits natural resources, as well as CO_2 emissions (European Commission, 2014).

Standards for environmental performance assessments such as ISO 14031:2013 Environmental management - Environmental performance evaluation - Guidelines (International Organization for Standardization, 2013) require construction

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companies to adjust their processes and the deployment of extraordinary resources for actions that may not have tangible business benefits (Gangolells et al., 2011).

Besides this standard, the growing awareness about the negative impacts generated by the construction industry has led to the use of Environmental Assessment Methods (EAM). These rating schemes were developed and progressively updated with the intent to certify the environmental sustainability of buildings. Some examples of these rating schemes are Building Research Establishment's Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Green Star and Comprehensive Assessment Scheme for Built Environment Efficiency (CASBEE) (Doan et al., 2017). Also, LCA calculations are closely aligned with the European Commission Level(s) framework to improve the sustainability of buildings (European Commission - Environment, 2018).

Generally, the EAM assesses the buildings sustainability performance through the entire life cycle, from the design, construction, operation and maintenance to refurbishment. In each phase, most of the EAM evaluate the environmental impact generated by the selected products, health and safety of the occupants, management of the waste, energy, wastewater and transportation (Biswas et al., 2008; Doan et al., 2017). In this way, it is possible to assess the environmental impact, quantify the carbon emissions throughout a building's life cycle and thus, helping stakeholders to improve the buildings' performance with full knowledge regarding the solutions to implement and its impacts (Cole, 2010).

The current processes for the identification and quantification of construction projects environmental impacts usually emphasize the analysis of energy use and applied products. Notwithstanding, these processes are concentrated before the on-site construction start to evaluate the future impacts on the following phases based on two methods:

- Life cycle assessment (LCA) methodology (Abd Rashid and Yusoff, 2015; Bilec et al., 2009; Cabeza et al., 2014; Li et al., 2010; Van Den Heede and De Belie, 2012; Wang et al., 2017)
- Hybrid models of LCA (Bilec et al., 2009; Treloar et al., 2000; Sharrard et al., 2008).

Likewise, there are other methodologies to predict the severity of environmental impacts related to the construction process (Fuertes et al., 2013; Gangolells et al., 2009, 2011). Specific studies such as González and Navarro (2006) seek to evaluate the reduction of CO_2 emissions in the construction field through the selection of products.

In general, some impact factors are not evaluated because they were considered unimportant in previous studies or probably were only ignored (Treloar et al., 2000). When applying EAM, it is possible to access more fields, which have an impact on the environment and on the definition of the building's strategies.

Existing research on initial embodied impacts of construction projects focused mostly on the assessment of products, vehicles and machines, without establishing any quantitative assessment of the workers' correlated impact factors. At the same time, a minimal number of studies tried to quantify workers wastewater produced during the construction-installation process. Hence, the work presented in this paper contributes to the body of knowledge by developing a methodology to quantify workers' (a) GHG emissions and, (b) sanitary wastewater generation. Consequently, this work provides a new methodology based on the workforce's Labour-hour (L.h) productivity for assessing environmental impacts in the construction industry.

2. Background

Life cycle assessment is considered as the only legitimate basis for comparing environmental impacts of alternative building products and services. Life cycle assessment aims to identify and quantify environmental impact factors associated with a process.

Environmental factors are identified and calculated for each phase of a product's life cycle (Treloar et al., 2000). González and Navarro (2006) analysed CO_2 emissions produced during the construction of a building in order to predict a possible reduction of these emissions through an adequate selection of products. Their study estimates CO_2 emissions in kg per CO_2/kg for each product in the construction according to tasks and compositions, as examples: concrete; steel; ceramic; and glass (González and Navarro, 2006). Studies conducted on CO_2 emissions into conventional masonry and light steel frame found that infrastructure and superstructure tasks contribute to more emissions because of the high consumption of concrete, coarse steel aggregates, and wood. According to EN 15978:2011, the embodied impacts are connected with almost all phases of a Building's Life Cycle except for the "B6" (Operational Energy Use) and "B7" (Operational Water Use) ones, and this is related to operation impacts (IEA, 2016; Vilches et al., 2017). Table 1 presents the Building Life Cycle and the boundaries system (IEA, 2016).

The present workers-emission-based study sits at the Construction process stage, specifically "A5" Construction-Installation Process (Table 1). According to a Joint Research Centre (JRC) report, in EU-28 craft and trade workers account for 56% of construction industry employment (Desruelle et al., 2019). At the same time, all the effort of designing and planning work-teams focus their deliverables to the construction-installation phase. Furthermore, managers and supervisors spend their work-hours on-site. The presented method may fit to quantify any activity carried out by human resources. It applies to all stages of a buildings' life cycle to quantify workers' emissions share.

Table 1. Building Life Cycle and Boundaries System (IEA, 2016)

Building Life Cycle																***Additional information***
Product stage			***Construction process stage***		***Use stage***							***End of life stage***				***Potential benefits loads***
A1	***A2***	***A3***	***A4***	***A5***	***B1***	***B2***	***B3***	***B4***	***B5***	***B6***	***B7***	***C1***	***C2***	***C3***	***C4***	***D***
Raw material supply	***Transport***	***Manufacturing***	***Transport***	***Construction-Installation process***	***Use, installed products***	***Maintenance***	***Repair***	***Replacement***	***Refurbishment***	***Operational energy use***	***Operational water use***	***Deconstruction***	***Transport***	***Waste processing***	***Disposal***	***Recovery, Reuse, Recycling, Potential***
Embodied	Embodied	Embodied	Embodied	Embodied	Embodied	Embodied	Embodied	Embodied	Embodied	Operational	Operational	Embodied	Embodied	Embodied	Embodied	Embodied + Operational
Cradle to Gate																
Cradle to Site																
Cradle to Handover																
Cradle to End-of-Use																
Cradle to Grave																
Cradle to Grave (including net benefits and loads beyond the system boundary as additional information)																

In order to quantify the initial Embodied GHG emissions, the EN 15978:2011 introduces a calculation procedure based on the measurement of construction products and the correlation of an LCA database coefficient (IEA International Energy Agency, 2016). First of all, the systemic multiplying quantities of products (kg per CO_2/kg) related unit of the element provides the amount of CO_2 emissions in the Cradle to Gate (Product Stage).

Second, in order to achieve the embodied impact until the Cradle to Site boundary, it is required to add the product delivery on the construction site. There are two ways allowed: I. Calculating distances of each delivery and multiply it by a transport coefficient; II. Adding a percentage allowance (e.g. 5 - 10%). Finally, grounding the Cradle to Handover requires adding the site activities. In order to calculate this embodied impact, the system indicates the use of contractors' historical data or, as an example of the last item, the addition of a percentage allowance (e.g. 5 - 10%) (IEA, 2016). After that, based on the initial embodied impact determination, one may find the total embodied impact over the life cycle. It is important to emphasise that in a superior or lower level the construction-related workforce is present in a Building's Life Cycle. As evidenced above, calculation procedures based on the EN 15978:2011 do not highlight the workforce impact, just point to historical data or attribute a relative percentage (IEA, 2016). Gangolells et al. (2009) developed a methodology to predict the severity of environmental impacts related to the construction process of residential buildings. The method addresses the identification of environmental aspects related to the construction process, as:

- emissions to the air;
- emissions of wastewater, treatment of solid and other wastes;
- use and contamination of land;
- use of natural resources and raw materials;
- local problems (e.g. noise, vibration, dust, visual appearance);
- transportation problems, risk of environmental accidents, effects on biodiversity.

It should be noted here that what is used is the average number of workers per day at the construction site, and this is the input for the evaluation of discharging sanitary wastewater resulting from sanitary conveniences at the construction site (Gangolells et al., 2009). Nevertheless, this daily average value can lead to significant distortions, as during a project and depending on the worksite, the number of workers may suffer high variations. The non-linearity of the workforce during a project is, most of the times, a granted aspect. Besides, Gangolells et al. (2009) method does not use a volume quantification of sanitary wastewater discharge. This is achieved through a severity index that is presented. A similar situation occurs with the CO_2 emissions from workers breathing.

Fuertes et al. (2013) developed a causal model of environmental impact-oriented to construction processes, considering the following pertinent factors: tasks, construction sites, equipment, products and, workers. The generation of greenhouse gas emissions, fuel consumption or noise, is directly related to the use of machines and construction equipment during the activities' execution (Fuertes et al., 2013).

However, concerning impacts on the environment, standardization (EN 15978: 2011) only focuses on CO_2 emissions with emphasis on the use of natural resources and raw materials. Other studies subjectively assess other factors more connected to the construction phase, such as soil contamination, local disturbances due to noise and dirt, and risks of transport accidents. Undoubtedly, environmental impact factors in the Construction-Installation process (A5) also relate to machinery and equipment (e.g. vibration, fossil fuel consumption, and oil leaks). These variables are heterogeneous from site to site and highly dependent on the machinery being used. However, other factors, such as waste treatment and recycling, relate to the culture and education of workers, which varies widely depending on the geographic location of the construction site. This implies a gap for a more detailed assessment of environmental impacts generated by workers, summoning an increase of knowledge about the construction phase. Despite of this exposed issues, the present work focuses on assessing the impacts caused directly by the workforce: CO_2 and sanitary wastewater emissions. In order to depict this, the paper aims to deliver a detailed analysis of on-site tasks approach. Significantly, as already presented, craft workforce accounts for more than half of the human resources employed in the construction industry. The analysis of a building's life cycle is complex and influenced by multiple factors, and the need for manual/craft production in the construction industry is strong, and it will remain so for the years to come.

3. Method

The methodology conceptualises the direct relationship between worked-hours to CO_2 and sanitary wastewater emissions. Section 4 presents the formulation of this concept that relates both to the emissions of craft workers and office workers. Bearing in mind that craft workers carry out activities of higher physical effort and that this condition increases both the exhalation of CO_2 and affects a more significant generation of wastewater, different analysis for each group is presented. The proposed Labour-hours emissions indexes for both craft and office workforce will correlate worked-hours with the emission of kg of CO_2 and the emission of litres of sanitary wastewater.

Case studies are presented in section 5. Both sample the direct determination of emissions based on human resources allocated to engineering projects, as well as a detailed analysis of different types of construction tasks. This analysis seeks to indicate that the choice or type of task, in addition to influencing the emissions relevant to the products, also causes different amounts of workers related emissions. Moreover, LCA studies may incorporate this approach into engineering projects.

In order to measure the impact from lower productivity, industrial assembly activities comparison was carried out by Brazilian and American workers. A detailed analysis of fourteen typical construction tasks (e.g. flooring, concrete, metallic structures) is carried out based on the details of product consumption, equipment, and human resources indicated by the unit pricing system of CYPE Ingenieros (CYPE, 2018). Subsequently, the calculation of emissions is performed based on the multiplication of these quantities by the indexes regarding the products (González and Navarro, 2006) and craft workers (Labour-hours indexes determined in this study).

Finally, in terms of craft workforce productivity, typical tasks in the industrial construction are evaluated: the assembly of metal structures, equipment, and piping. In order to perform this analysis, the authors only compared labour indexes from Brazil to the USA (Kardec and Simonsen, 2004), not considering emissions by the materials. It is worth noticing that the number of indirect workers is proportional to the number of craft workers. Thus, an increase in craft workforce increases the necessary number of the office workforce (management).

4. Labour-hours factor as input-output for the environmental impact assessment

4.1. Concept

According to Sink (1985) productivity in the construction industry can be measured through the ratio between the quantity (according to with pre-defined measurement criteria) of each construction task and the necessary human, material and financial resources in each of these tasks. Extremely used in construction, the Man-hour factor (M.h) is an index that represents the number of human resource hours required to complete the tasks that integrate the scope of an engineering project (Sink, 1985). In this work, in order to avoid potential gender discrimination, the term Labour-hour (L.h) is nominated instead of the well-known Man-hour.

The size and nature of the construction project (e.g. residential buildings, highways, industrial plants) impacts on the quantity and type of services to be carried out, therefore impacting the forecast of required Labour-hours. Two factors determine the amount of L.h in projects: the number of services to be performed and their estimated/realised productivity. A larger project with lower productivity engenders a higher number of Labour-hours required. However, for the implementation of a project, after an efficiency estimation (expected productivity), it is necessary to allocate the human resources. There are two types of actions in terms of planning and, consequently, determining their duration: resources regularization or levelling. Resources regularization consists of using the margins of non-critical activities in order to improve the distribution of resources, without changing the total duration of the project. This action usually involves the addition of constraints and an increase in the number of critical activities. The resources were levelling consists of relaxing the program so as not to exceed certain limits on labour loads, due to different requirements. Usually, in this case, there is an increase of work length. There are no objective methods of resources regularization. However, it may be possible to regularize some resources without the capacity for simultaneous optimization of all. Nevertheless, there is a heuristic resources levelling method.

The worker-emission-based method mainly focuses on quantifying the environmental impact of the craft workforce directly used to carry out the activities within construction sites. Once these represent the most significant number of L.h (define lead time boundaries), and they are directly impacted by the specifications and requirements of products and processes defined in the pre-design and design phase. The postulated method will, however, be also presented to estimate the impact of the indirect "office "workforce that supports projects (e.g. designers, managers and supervisors).

4.2. Labour-hour emissions indexes method

A volume of 75 litres per day of sanitary wastewater per employee in industrial activities, and 50 litres per day per employee in office activities are estimated for the sanitary wastewater discharge, resulting from sanitary conveniences (Santo, 2008). Based on an 8-hour workday, we determined that one worker in direct construction-site duty emits 9.375 litres of sanitary wastewater per working hour. Moreover, also based on an 8-hour workday, one worker in indirect construction activities emits 6.250 litres of sanitary wastewater per 1 hour of work.

Regarding CO_2 emissions, Table 2 (ToolBox, 2004) presents the amount of CO_2 emissions per person based on the intensity of activity performed. Furthermore, this methodology presumes the index of 1.79791 kg/m^3 of CO_2 (ICBE, 2018) for the construction industry activities accounted for.

The indirect workforce has most of the activities performed in the office. It was considered in Eq. (1) the value of 0.0200 m^3/h for low work activity directly based on Table 2 (ToolBox, 2004):

$$OW - L.h\ index = R - LWA * 100\% * CO_2\ index \qquad (1)$$

where: *OW-L.h index* – Labour-hour index of emission of kg of CO_2 by office workforce; *R-LWA* – Resting or low work activity; *CO_2index* – Index of 1.79791 kg/m^3 of CO_2.

Notwithstanding, in order to estimate CO_2 emissions from craft workforce, due to activity singularity, it was applied a weighting factor on the values from Table 2. According to Adrian (2004), craft workers in the construction industry are between 15 to 20% of the time in idleness. Moreover, assumptions and practical studies point to several other factors that generate unproductiveness, as well as the need to perform auxiliary activities, which lead to a practical maximum performance of 60% of the overall time (Adrian, 2004). Furthermore, assuming that during 20% of the workday, employees are resting or in low work activity, 20% of the time in normal-impact work, and in the other 60% of the time in high-impact work performance. It is worth noticing that the present model foresees some calibrations related to the type of construction, inherent to peculiarities or craft workers' labour performance different estimation. That is possible by a simple re-weighting of the values contained in the weight factor used, 20% (Resting or low work activity) plus 20% (Normal work activity) plus 60% (High work activity). Based on that, it is estimated that the craft workforce in construction activities emits an average of 0.2370 m^3/h of CO_2 (Eq. 2):

$$CW - L.h\ index = (R - LWA * 20\% + HWA * 60\% * CO_2\ index \qquad (2)$$

where: *CW-L.h index* – Labour-hour index of emission of kg of CO_2 by craft workforce; *R-LWA* – Resting or low work activity; *NWA* – Normal work activity; *HWA* – High work activity; *CO_2index* – Index of 1.79791 kg/m^3 of CO_2.

Based on the above detailed: each 1 L.h of the office workforce emits 0.03596 kg of CO_2; each 1 L.h of craft workforce emits 0.42611 kg of CO_2. In summary, each 1 L.h of office workforce emits 6.250 litres of sanitary wastewater and 0.03596 kg of CO_2. Likewise, for each 1 L.h of the craft workforce emits 9.375 litres of sanitary wastewater and 0.42611 kg of CO_2. From these estimations and assumptions results the craft workforce emits 33% and 1185%, respectively, more litres of sanitary wastewater and kg of CO_2 than the office workforce. The Labour-hour emissions indexes are presented in Table 3.

5. Application cases of the environmental impact generated by construction industry workers

5.1. Generic approach

Determining the environmental impact generated by workers in the construction phase is suitable as a preliminary planning phase, considering the presented method, and it may be precisely determined after the project's end. There are different ways in order to determine the total amount of labour-hours required for a project or building stage. For instance, based on a twin project, it is possible to infer some human resources equal to the previous one. Furthermore, the managers' experience or a fixed allocation of human resources over time may base the estimation of labour-hour required for a certain task.

As an example, the estimation for a small building rehabilitation service where ten craft workers have worked an entire month (considering: 220 hours per month per craft worker, results in a total estimate of 2,200.00 M.h).

Table 2. Emission of CO_2 per person based on the intensity of activity (ToolBox, 2004)

Activity Level	*Breathing per person (m^3/h)*	*Emission of CO_2 per person (m^3/h)*
Sleeping (SL)	0.300	0.013
Resting or low work activity (R-LWA)	0.500	0.020
Normal work activity (NWA)	2.500	0.100
High work activity (HWA)	7.500	0.355

Besides, the work of one fulltime manager plus one designer for a one-week period (considering: 180 hours per month per indirect worker, results in a total estimate of 225.00 M.h). Hence, the craft workforce may present emissions of 20,625.00 litres of sanitary wastewater and the emission of 937.44 kg of CO_2. Moreover, indirect workforce (manager plus designer) present emissions of 1,406.25 litres of sanitary wastewater and the emission of 8.09 kg of CO_2. The sum totalizes, for this hypothetical project, the emission of 22.031.25 litres of sanitary wastewater and the emission of 945.53 kg of CO_2.

Table 3. Labour-hour emissions indexes

Labour-hour index	*Craft workforce*	*Office workforce*
Emission of kg of CO_2	0.42611	0.03596
Emission of litres of sanitary wastewater	9.37500	6.25000

However, in practice, if a change in resource allocation or execution time appears, the previously estimated value can be adjusted based on the model. Thus, considering the same example presented before, in order to accomplish the one-month deadline, the manager had to allocate another craft worker for the last two weeks. This required adjustment results in a total craft workforce of 2,310.00 L.h (2,200.00 L.h + 110.00 L.h), and therefore on the real generation of 23,062.50 litres of sanitary wastewater and the emission of 992.41 kg of CO_2.

Still, more complex processes of task budgeting count on a significant level of detail. The estimation of indirect workforce necessary to carry out a building resembles to the project's size and firm's expertise. On the other hand, the determination of craft workforce amount of hours requires detailing the scope and the calculation of indicators to quantify each performed task.

5.2. Detailed approach

Tables for unit price formation detail each task by decomposing them into products, equipment and human resources. As an example, the price generator for civil construction provided by CYPE *Ingenieros* (CYPE, 2018) has been publishing the composition of work tasks productivity and indexes for European countries as Portugal, Spain or France and other 24 countries in America and Africa. The tasks inherent to the construction phase are broken down item-by-item with the respective yield on products, equipment, and human resources.

Through the evaluation of the labour productivity income, it is possible to determine the Labour-hour of each planned task in the construction-installation phase. In this sequence, Tables 4, 5, 6 and 7, develop simulations based on the established assumptions regarding craft workforce CO_2 emission and dumping sanitary wastewater, applying some of the productivity indexes compositions disclosed by the CYPE company.

Table 4. Unit composition of tasks in flooring: consumption/productivity (CYPE, 2018), products emissions indexes (González and Navarro, 2006), and Labour-hours emissions indexes (Table 3)

Task (unit)	*Resources*	*Consumption /Productivity (a)*	*Emissions indexes (CO2[c] and sanitary wastewater[d]) kg.CO2/kg (b)*	*Emission of kg of CO2 ($a * b^c$)*	*Emission of litres of sanitary wastewater ($a * b^d$)*
Flooring with ceramic tile					
(ton)	Ceramic	1.0000	0.0404	40.4000	
(ton)	Cement	0.6516	0.1260	82.1053	
(L.h)	Labour-hours	94.4862	0.42611[c] 9.37500[d]	40.2615	885.8083
Floor with natural stone flooring on a flat surface					
(ton)	Natural stone floor slabs	1.0000	0.0953	95.3000	
(ton)	Cement	0.1465	0.1260	18.4615	
(ton)	Cement rendering	0.0027	0.1260	0.3462	
(L.h)	Labour-hours	13.2234	0.42611[c] 9.37500[d]	5.6346	123.9698
Floor with artificial stone flooring on a flat surface					
(ton)	Artificial stone	1.0000	0.0404	40.4000	
(ton)	Cement	0.1465	0.1260	18.4615	
(ton)	Cement rendering	0.0027	0.1260	0.3462	
(L.h)	Labour-hours	13.2234	0.42611[c] 9.37500[d]	5.6346	123.9698

Table 5. Unitary composition of tasks in concrete (assembling of prefabricated): consumption/productivity (CYPE, 2018), products emissions indexes (González and Navarro, 2006), and Labour-hours emissions indexes (Table 3)

Task (unit)	*Resources*	*Consumption /Productivity (a)*	*Emissions indexes (CO2[c] and sanitary wastewater[d]) kg.CO2/kg (b)*	*Emission of kg of CO2 (a * b[c])*	*Emission of litres of sanitary wastewater (a * b[d])*
Beam of reinforced concrete (assembling of prefabricated)					
(ton)	Reinforced concrete	1.0000	0.0194	49.2301	
(hour)	Equipment	0.1133	-	-	
(L.h)	Labour-hours	0.3400	0.42611[c] 9.37500[d]	0.1449	3.1875
Column of reinforced concrete (assembling of prefabricated)					
(ton)	Reinforced concrete	1.0000	0.0194	43.4973	
(hour)	Equipment	0.3886	-	-	
(L.h)	Labour-hours	1.1703	0.42611[c] 9.37500[d]	0.4987	10.9714

Table 6. Unitary composition of tasks in concrete (manufactured in central): consumption/productivity (CYPE, 2018), products emissions (González and Navarro, 2006), and Labour-hours emissions indexes (Table 3)

Task (unit)	*Resources*	*Consumption /Productivity (a)*	*Emissions indexes (CO_2[c] and sanitary wastewater[d]) kg.CO_2/kg (b)*	*Emission of kg of CO_2 (a * b[c])*	*Emission of litres of sanitary wastewater (a * b[d])*
Beam of reinforced concrete (manufactured in central)					
(ton)	Concrete	1.0000	0.0194	19.4000	
(ton)	Steel	0.0577	0.5168	29.8301	
(ton)	Wood	0.0046	0.0000	0.0000	
(L.h)	Labour-hours	3.2221	0.42611[c] 9.37500[d]	1.3730	30.2071
Column of reinforced concrete (manufactured in central)					
(ton)	Concrete	1.0000	0.0194	19.4000	
(ton)	Steel	0.0466	0.5168	24.0973	
(ton)	Wood	0.0367	0.0000	0.0000	
(L.h)	Labour-hours	7.6137	0.42611[c] 9.37500[d]	3.2443	71.3786
Solid slab of reinforced concrete (manufactured in central)					
(ton)	Concrete	1.0000	0.0194	19.4000	
(ton)	Steel	0.0338	0.5168	17.4662	
(ton)	Wood	0.0044	0.0000	0.0000	
(L.h)	Labour-hours	2.8238	0.42611[c] 9.37500[d]	1.2033	26.4732
Ladder of reinforced concrete (manufactured in central)					
(ton)	Concrete	1.0000	0.0194	19.4000	
(ton)	Steel	0.0196	0.5168	10.1476	
(ton)	Wood	0.0190	0.0000	0.0000	
(L.h)	Labour-hours	3.1968	0.42611[c] 9.37500[d]	1.3622	29.9698

It can be verified that there is considerable variability in the relation kg of CO_2 per kg of construction products applied in different studies. For that reason, only González and Navarro (2006), will be used as a source, as forward evidenced:

- concrete (mass concrete 30 MPa) 0.0194 kg.CO_2/kg;
- steel 0.5168 kg.CO_2/kg;
- wood (air-dried) 0.0000 kg.CO_2/kg;
- ceramic 0.0404 kg.CO_2/kg;
- cement and rendering 0.1260 kg.CO_2/kg;
- natural stone floor slabs 0.0953 kg.CO_2/kg;
- artificial stone 0.0404 kg.CO_2/kg.

5.2.1. Composition of tasks in flooring

For the execution of one ton of floors, three different tasks are simulated. One with ceramics and the others with stone, both natural and artificial, see Table 4. Flooring with ceramic tile obtained the highest values of emissions, 885.81 litres of sanitary wastewater and 162.77 kg of CO_2, of which this 40.26 kg of CO_2 (24.74%) are emissions from the craft workers.

For the execution of stone floors, the difference between the activities is only referring to the use of natural or artificial stone. Once the quantity of craft worker is the same in both cases, the sanitary wastewater emission value is 123.97 litres and the CO_2 5.63 kg for both. However, when the task is natural stone flooring on a flat surface, the CO_2 emission by the craft workforce represents 4.71% of the total 119.74 kg of CO_2. The same with artificial stone results on craft workers CO_2 emission representing 8.69% of the total 64.84 kg of CO_2.

By comparing only, the environmental impact of the products in the three options, it is verified that the activity with artificial stone (59.21 kg of CO_2) is the less offensive. At the same time, there is a small difference between natural stone (114.11 kg of CO_2) and ceramic (122.51 kg of CO_2). However, when adding to the analysis the emissions by the craft workers, the task in ceramics contributes with 885.81 litres of sanitary wastewater, which is 714% higher compared to 123.97 litres of the others tasks that use stone. Also, due to the higher demand for craft workforce on the task in ceramics, it reaches a total emission of 162.77 kg of CO_2, 251% and 35.89% higher respectively, for the tasks in artificial and natural stone.

5.2.2. Composition of tasks in concrete

In order to evaluate the performance of reinforced concrete tasks, it was considered one ton of concrete (for assembling of prefabricated concrete, see Table 5, and for concrete on-site execution, see Table 6), and different structural elements as a beam, column, solid slab, and ladder. Regarding the products' impact, it is observed that what most influences environmental impact is the density of steel in the different reinforced concrete structural elements.

The required Labour-hours is connected to the complexity level of each one of these structural elements. It should be stressed that the execution of a reinforced concrete column demands more than the double in terms of craft workforce time (for the same number of workers) than other structural elements. Therefore, it is the task with higher environmental impact factor, 71.38 litres of sanitary wastewater and 3.24 kg of CO_2 per ton of concrete placed in columns (only of Labour-hours point of view).

In concreting tasks, CO_2 emissions from the craft workforce compared to total emissions represent 2.71%, 3.16%, 4.41% and 6.94% respectively in beams, slabs, ladders and columns. Pre-fabricated reinforced concrete only fit in on-site assembly tasks, and it can be observed that the demand for Labour-hours is not very expressive. The CO_2 emissions from the craft workforce in prefabricated concrete compared to total emissions of concrete manufactured in central represent just 0.29% and 1.13% respectively in beams and columns.

It should be noted that the relevant craft workers emission for these tasks may not have occurred on the construction site, which means that during elements manufacturing, there are emissions to be considered. Therefore, they must be added to those that occur on-site to allow a compatible analysis.

5.2.3. Composition of tasks in Metallic Structures

Following it is evaluated the execution of one ton of metal structures. Five different services in civil construction are analysed as detailed in Table 7. A clear connection can be made between the complexity of the tasks, the demand for human resources and the relevance of the environmental impacts. The assembly of medium/heavy structures involving high mechanisation in the process requiring fewer Labour-hours. Contrasting, the assembly of light structures with many details (e.g. platforms), will demand a higher amount of Labour-hours.

In the Self-supporting light metal structure task, the total emissions reach 1,147.50 litres of sanitary wastewater and 568.96 kg of CO_2, where 9.17%, 52.16 kg of CO_2 are correlated to emissions by the craft workforce.

Table 7. Unit composition of tasks in Metallic Structures: consumption/productivity (CYPE, 2018), products emissions (González and Navarro, 2006), and Labour-hours emissions indexes (Table 3)

Task (unit)	***Resources***	***Consumption /Productivity (a)***	***Emissions indexes (CO2^c and sanitary wastewater^d) kg.CO_2/kg (b)***	***Emission of kg of CO_2 (a * b^c)***	***Emission of litres of sanitary wastewater (a * b^d)***
Self-supporting light metal structure					
(ton)	Steel	1.0000	0.5168	516.8000	
(L.h)	Labour-hours	122.4000	0.42611^c; 9.37500^d	52.1559	1147.5000
Metal structure for roofs					
(ton)	Steel	1,0000	0.5168	516.8000	
(hour)	Equipment	1.8667	-	-	
(L.h)	Labour-hours	30.5067	0.42611^c; 9.37500^d	12.9992	286.0000
Metal structure realized with porticos					
(ton)	Steel	1.0000	0.5168	516.8000	
(hour)	Equipment	1.0671	-	-	
(L.h)	Labour-hours	16.8293	0.42611^c; 9.37500^d	7.1711	157.7744
Metal structure (beams and columns)					
(ton)	Steel	1.0000	0.5168	516.8000	
(hour)	Equipment	46.0000	-	-	
(L.h)	Labour-hours	62.0000	0.42611^c; 9.37500^d	26.4188	581.2500
Steel in work platform structure					
(ton)	Steel	1.0000	0.5168	516.8000	
(hour)	Equipment	14.2857	-	-	
(L.h)	Labour-hours	426.6667	0.42611^c; 9.37500^d	181.8069	4000.0000

Table 8. Productivity in heavy construction in Brazil and the USA: productivity (Kardec and Simonsen, 2004), and Labour-hours emissions indexes (Table 3)

Country	***Brazil***	***USA***	***Labour-hours emissions indexes***		***Brazil***	***USA***	***Brazil***	***USA***
Description	***Productivity in M.h per ton***		***L.h/kg***	***L.h/litre***	***Emission of kg of CO_2***		***Emission of litres of sanitary wastewater***	
	(a)	***(b)***	***(c)***	***(d)***	***(a * c)***	***(b * c)***	***(a * d)***	***(b * d)***
Assembling of equipment	18.5000	15.0000	0.42611	9.37500	7.8830	6.3917	173.4375	140.6250
Assembling of metal structures	50.0000	30.0000	0.42611	9.37500	21.3055	12.7833	468.7500	281.2500
Manufacturing of pipe (8” sch40)	109.5000	71.1000	0.42611	9.37500	46.6590	30.2964	1026.5625	666.5625
Assembling of pipe (8” sch40)	163.8000	106.4000	0.42611	9.37500	69.7968	45.3381	1535.6250	997.5000

The CO_2 emissions from craft workforce compared to total emissions represent 1.37%, 2.45%, 4.86% respectively in the tasks of Metal structure realised with porticos, Metal structure for roofs and, Metal structure (beams and columns). In the steel in work platform structure task, it is determined the most prominent total emission for one ton of metal structure. As a result, totalizes 4,000.00 litres of sanitary wastewater and 698.61 kg of CO_2, where 26.02%, 181.81 kg of CO_2 are connected to emissions by the craft workforce.

5.3. Potential environmental impacts from craft workforce on industrial plants assembly tasks

Regarding craft workforce potential environmental impacts on industrial plants assembly tasks, and highlighting the influence from productivity on the environmental damage, task production indexes data from Brazil and the United States of America were confronted (Kardec and Simonsen, 2004), see Table 8. As noted, the execution of a task in a developed country, with higher productivity, potentially allocates fewer human resources (Labour-hours) than the same task in developing countries. Therefore, that activity will have a lower environmental impact. Consequently, it becomes clear the environmental impact differences caused by the distinct labour productivity in Brazil compared to the USA. Both CO_2 and sanitary wastewater emissions are approximately 19% higher on the Assembly equipment, approximately 35% higher in the Manufacturing and Assembling of pipes tasks and, 40% higher in the Assembling of metal structures.

6. Conclusions

The determination of products and the analysis of tasks’ processes in the preliminary construction phases drive environmental damage factors concerning the emissions to the air, wastewater and soil, energy consumption and human resources. It is possible to determine the amount of CO_2 emissions and the generation of sanitary wastewater based on the allocation of human resources in construction projects.

It is observed that the craft workforce impacts more on the environment than the indirect workforce. Craft workers who directly perform tasks on the construction sites potentially generate a volume in litres of sanitary wastewater that is 33% higher and emit 1185% more kg of CO_2 than workers who perform only administrative activities, typically in offices. The evaluation of the compositions of the productivity indexes for the construction tasks indicates that the influence of craft workforce on the greenhouse gas may be up to 26%. Furthermore, developing countries with lower productivity consequently produce a higher level of environmental damage.

It is clear from the magnitude of the emission values from artisanal workers (33% and 1185%) that the work carried out in the construction phase is relevant to LCA studies, and that these values are more significant than those from these workers if they were at home. Take the example of the decrease in pollution rates during the confinement (COVID-19) period of people at home away from their jobs.

The determination of construction workers environmental impact through the Labour-hours factor is assumed as an agile and straightforward method that provides both comprehensive and detailed assessments across different types and sizes of engineering projects. This method may be complementary to current EAM and LCA methods, causal factor assessments and CO_2 emission based on a choice of products/constructive processes.

This methodology can also be valuable to evaluate the impacts of construction tasks mechanization, as with the introduction of machinery and equipment’s construction tasks tend to obtain higher productivity but the CO_2 emissions that result from that cannot be neglected. In this respect, the methodology streamlines comparisons or can forecast the benefits or the boundaries of tasks mechanisation to decrease environmental impacts.

Further research will concentrate on a more precise evaluation of the unit compositions of the different tasks that constitute engineering projects. In addition to human and products, impacts from transportation and equipment are essential aspects. Consequently, a more precise diagnosis will foster improved environmental impact analysis for each element in the context of the constructive processes.

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