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Life Cycle Inventory of Ceramic Brick, Concrete Block and Construction and Demolition Waste Brick: Case Study in Belo Horizonte, Brazil

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The expansion of the recycling market basically depends on making the use of recycled aggregates viable. In that direction strategies and scientific methodologies are welcome to meet the Agenda 21. However, it is difficult to find appropriate measurement methods. For this reason, creating databases that associate the life cycle of materials and processes with consumption and discard of the materials could be a starting point in supporting environmentally up-to-date choices. Carbon dioxide stands out among the impacts of construction materials. Carbon footprint is a subset of the Life Cycle Assessment study, and in the present political context, in general in countries in the Northern Hemisphere it is one of the most-used factors in the decision process regarding sustainable consumption and production. The objective of this article was to show the first approximation about the develop an inventory of bricks made with construction and demolition waste in Belo Horizonte in the Brazilian state of Minas Gerais, and Compared to the other blocks: concrete, ceramic. The material components of the life cycles of the agents involved in this study were input into Umberto software, defining the unit for each type of material separated into groups (work folders in Umberto). These work folders were created for energy, emissions, raw materials, supply and other items, and flow networks are presented. Three different scenarios were created: the ceramic brick manufacturing scenario; the concrete block manufacturing scenario; and the CDW block manufacturing scenario. This first study, the inventory is fundamental for the directives of Life Cycle Assessment in Belo Horizonte. Using this starting point, a comparison is made between the production process inventory of concrete blocks and ceramic bricks. This comparison was related only to CO_2 emission parameters. The following methods were used for this: Life Cycle Assessment (LCA) with reverse logic to obtain data from the point of consumption to the point of origin. Supplies for manufacturing ceramic block, concrete block, and extraction of non-renewable resources are taken from literature. Flow networks were developed for both processes on Umberto software and were compared. The objectives, scope, functional unit, systems, limits and results of this LCA are presented graphically and with a Sankey diagram with discussion. The main contribution of the article refers to sustainable use when considering choice of construction material with less environmental costs through the lens of "carbon footprint".

Keywords: life cycle assessment (LCA), sustainability, construction and demolition waste (CDW), CO_2, construction materials.

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Introduction

Managing and recycling CDW

Various parties are involved in the brief; design; raw material extraction, transport and processing; construction materials production and distribution; construction; use, repair and maintenance; demolition; disposal, reuse, or recycling of built environment, their cooperation taking rather long period of time. Life cycle efficiency of built environment depend to a very great extent not only on the selected most rational processes and solutions (Kaklauskas, 2016).

In the recent past, the construction sector is responsible for various environmental impacts, such as the intense use of non-renewable natural resources and generation of a large amount of solid waste (John, 2000). According to Rocha & Cheriaf (2003), interest in construction waste focuses on two factors: the fact that the chemical make-up of a large majority of the waste is silicates, aluminates and alkaline oxides, the same basic compounds that make up construction materials; and the significant volume of waste created by the process every year, which could be used as raw materials used in manufacturing the materials used in construction. Lithuania and Brazil are very next in their actions. Energy efficiency and renewable energy is considered of high priority followed by the reduction of toxic materials, indoor pollution and water saving (Vatalis et al. 2013).

Brazil is trying to follow the same CDW recycling philosophy, in the past Pinot (1999) states that this system is made up of: a) a network of strategically positioned collection points for small and large generators to make throwing the waste away unattractive; b) licensed transport companies; and c) CDW recycling. This was the vision adopted in CONAMA resolution number 307 in July 2002. This resolution assigned responsibilities to CDW generators, transporters and government offices. CDW was divided into four classes based on ability to recycle (A, recycled as aggregate; B, recycled in other chains such as plastics; C, no economically viable recycling technology exists) or the danger presented by the waste (Class D).

(Kubilius & Kazlauskas, 2009) explains the need for implementation of strategies for sustainable development. And that should be implemented in a period before 2020. This due to the rapid growth scheduled for Lithuania, and with that, on 15 May 2012 the Parliament of the Republic of Lithuania with its Resolution Nº XI-2015 adopted Lithuania's Progress Strategy "Lithuania 2030". This Strategy underlines the need for incentives for business to invest in green technologies, products and services (Ministry of Environment of the Republic of Lithuania, 2015). The anticipated rapid growth of consumption is expected to boost the use of primary energy, resulting in larger amounts of pollutants and greenhouse gases released into the atmosphere.

In the past, Brazil had no reliable records, a fact that hindered the development of public policies. In the Lithuania, too, there was no recording or reporting of waste generation or disposal in Lithuania during the Soviet time. However, after declaration of independence in 1990 Environmental Protection Department was established which initialized collection of statistical data on waste generation and management. Waste generation, treatment and disposal were recorded and reported according to the waste classification categories. These waste in 2004 account for only 4% of Average composition of MSW in Lithuania (Konstantinavičiūtė, et al 2014).

In contrast, in the European Union (EU), the amount of C&DW comes to 180 million ton per year, and in ten EU countries1 this waste stream constitutes more than 34% of the total waste. In Lithuania, 43% of all C&DW is mixed waste, while in the EU-15 it makes only 5% [2]. It is the best indicator, showing the inefficiency of sorting at the source (Miliūtė &Staniškis, 2006). However, Lithuania, in 2012, 564 286 tonnes of construction and demolition waste (CDW) were generated in Lithuania. It represents a 45% increase compared to 2010 (388 100 tonnes) (EC, 2015).

In Brazil, these solid wastes represent around 50% of all urban solid waste. With average per capita CDW generation at 500 kg/year (Pinto, 1999), a sum of 68.5 x 106 tons CDW/year can be estimated, since in Brazil around 137 million people live in urban areas. This generation of construction waste makes up about 40% of the waste picked up by public services every day in Belo Horizonte (SINDUSCON-MG, 2008).

The indicators adopted in this academic work are focused only on the quantitative analysis of carbon dioxide emissions, though Sustainable development indicators have been grouped based on the three main sustainable development sectors: environmental status, economic development and social development. Such a type of grouping is rather conditional as a small number of the indicators presented are trans-sectoral, characterising sector interaction.

In general, LCA, It also provides a reference for other countries or markets that are considering building environmental assessment methods for sustainable building policies (Wong and Abe 2014). The strategy used in the case study in Belo Horizonte, in particular LCA, approaches the strategy adopted by Lithuania, as waste treatment is also covered by this block (EC, 2015).

The life cycle of the built environment can be assessed taking into account many quantitative and qualitative criteria. One of them is 'Quality of Life in a Built environment' discussed further as a Vision for Lithuania (Kaklauskas, 2016). With the rapid growth of the city of Belo Horizonte, as was observed in Lithuania (Staniskis & Plepiene, 2006), introduces the need to share the principle of science, knowledge and technological progress. According to this principle, the development of different sectors and their branches must be based on modern scientific achievements, knowledge and the latest environment-friendly technologies. From that, Energy efficiency and renewable energy is considered of high priority followed by the reduction of toxic materials, indoor pollution and water saving (Vatalis et al. 2013).

In Lithuania, the key point to the success of green economy is education and investments in research and development (Stanikis, 2011). The preserved system of central heating in Lithuanian cities and towns has resulted in rather low concentrations of sulphur dioxide and carbon monoxide in ambient air. With elimination of leaded gasoline, lead concentrations in the cities and near highways have also decreased by several times. In the face of growing energy consumption and scarce consumption of renewable energy sources, nuclear energy prevented any marked increase in greenhouse gases throughout the independence period.

In contrast, in Brazil, the great challenge is to collect data to generate benchmarks, leading to a lack of environmental profiles for buildings and construction materials and products. This absence of information makes it more difficult to conceive of sustainable development established by Agenda 21. Note that the questions of environmental impact of materials and products aren't just tied to production but also use demolition and disposal.

The creation of inventories identifies when it is possible to improve processes, and the Life Cycle Assessment stands out as an excellent tool to minimize environmental impacts. This approach to life cycle is essential to evaluate and improve environmental performance of construction materials. In order to promote their reuse, three concepts must be observed: (a) guarantee safety and quality; (b) reduce environmental impact; and (c) increase cost effectiveness of future construction (Dosho, 2008). An optimization of open information is significant for further development of LCA databases (Takano et al. 2014). This allows objective comparison of quantified environmental performance for various metrics like kg CO_2e global warming potential (O'Connor and Bowick 2014).

In Brazil, construction and demolition wastes can be classified into four groups, taking into account the origin and type of waste. This classification is in Accordance with Resolution nº 307/2002 of CONAMA (National Environment Council), in the first prerequisite for the proper management of RCD's. Therefore, the CONAMA Resolution nº 307/02, initiated a series of activities involving the recovery of the RCD by encouraging the reuse Use of CDW aggregates in concrete blocks and recycling of the same (Alves et al, 2016).

CDW separation (Belo Horizonte, Minas Gerais, Brazil)

Though there are efforts and concern with selective demolition in Brazil, waste is still generated indiscriminately in construction, demolition and remodeling phases. Recycled aggregate produced is normally mixed; that is, it contains a mixture of concrete, ceramic, natural stone, and other materials, each of which has different characteristics. In class A recycling facilities, the only triage is visual and CDW is classified as gray (mainly cement-based waste) and red (mainly ceramic, soil, etc) (Fig. 1), which is a fairly inefficient process.

Fig. 1

Reception of rubble (a), manual CDW sorting in the Estoril recycling plant in Belo Horizonte, MG (b), Red CDW (c), and Gray CDW (d)

In these recycling facilities, CDW is visually classified, generally by color, which has been shown to be only slightly efficient to identify the differences in physical properties of recycled aggregates (Angulo *et al.*, 2003). Add to this that the current CDW classification as red or gray might not be significant in terms of variations in porosity and potentially mechanical resistance of aggregates. Large volumes of raw material (CDW) are also required to produce 1 m^2 of concrete blocks, as in the case study carried out at the Estoril CDW facility in Belo Horizonte (Surgelas, 2010).

Nevertheless, in the past, the use of CDW aggregates in cement-based products is highly recommended to achieve recycling (ANGULO, 2002). It is known that it is technically viable to use aggregates with controlled quality in concrete (HANSEN, 1992; ZORDAN, 1997; HENDRIKS, 2000).

Methodology

Sampling

Recycled CDW aggregates for production of CDW blocks were considered from the recycled plant located in the Estoril neighborhood of the city of Belo Horizonte in the state of Minas Gerais, Brazil. The mass of CDW aggregates was calculated based on a study by Fukurozaki & Seo (2004), who adopt the mass of 1,100 kg/m^3 of CDW. The capacity adopted for dumpsters of CDW was around 4.6 m^3 and there were 4,694 CDW loads received by the factory in 2008. For the ceramic brick and concrete block production process, the available literature was used. For the Life Cycle Evaluation, this includes defining the objectives, scope, functional unit, general approach of the system, limits, use of Umberto software and presentation of results graphically and use of Sankey diagrams. The phases of the life cycle include extraction of raw materials, processing and manufacture of blocks in the study. The material related to the inventory of the study and charts are be included in the fourth section (Life Cycle Inventory).

Life Cycle Assessment

Life Cycle Assessment is an “internationally” recognized methodology that allows understanding and analysis of environmental repercussions caused by a product or activity. It can lead to finding opportunities for improvement if the phases of a production system are considered, according to Ferreira (2004), and contribute to reducing CO_2 emissions. According to John (2005), the criteria for selecting healthier materials, components and systems for construction include incorporated energy, socioeconomic materials and use of the Life Cycle Assessment (LCA) as a tool to quantify and compare results.

However, a LCA doesn't determine which process or product used is more expensive, cheaper or performs better. The information produced should be utilized to support the decision-making process in the regional environmental setting. The present study uses Umberto software.

Umberto software

Umberto is an environmental administration computer program that models, calculates liquid flow of materials and energy and illustrates Life Cycle Assessment by means of graphs or tables. It is one of the main LCA programs in Europe. It is used by companies, universities, consultants and research institutes (UMBERTO 2008). With this model, it is possible to identify interdependence between opportunities to save resources and energy in a company's environmental management plan. The results can be presented using a Sankey diagram. This is a material flowchart in which the flow quantity is represented by arrows with width proportional to mass or energy.

Functional Unit

In this work, the functional unit established was 1 m^2 of block-product, for the purpose of internal shoring of environments in a building.

Results analysis

Life Cycle Inventory (LCI)

Data Quality

For the time covered, the year 2008 was considered. Use of a one-year period was based on Vigon *et al* (1993). They also cautioned that the time period should be long enough to encompass abnormal behavior, for example, machine or work stoppages, and the authors considered one year to be sufficient. Other coverages present in a Life Cycle Assessment are geographical and technological. In the present study, the south and southeast region was chosen for geographic coverage and for technology, hand made or low volume production. Precision, uncertainty, integrity and representativeness of data are found in Surgelas (2010).

Diesel emissions factors

As far as the emissions factors of diesel combustion motors used in load-transporting vehicles, this research considers directives as in Prado (2007) and Brazil (2006) expressed in the first Brazilian inventory of human greenhouse gas emissions, a reference work published in 2006. This data was entered in Umberto software.

Estimate of hours worked in the CDW processing plant

The Estoril CDW recycling plant publishes official data regarding work hours, 855 hours/year working and 825 hours/year stopped, and for the CDW plant, 1099 hours/year worked. The stopped hours are due to maintenance, weather, Saturdays, Sundays, holidays and situations that weren't described in this work. Electrical energy and diesel consumption of the machinery was calculated from this data in function of hours worked in each step of the plant process.

Electrical energy

In general, with respect to electrical energy, the voltage of the machine was multiplied by the hours worked in the plant, in direct proportion to the quantity of CDW processed. The calculation procedure is expressed in equation 1, approximate values.

$$C_{equip} = Vol_{equip} . h_{tu} \tag{1}$$

where:

Vol_{equip} – equipment voltage (kW); Pot_{equip} – Power Equipment (kW); h_{tu} – Hours worked in the plant (h);
C_{equip} – Electrical energy consumption of the equipment.

Using reverse logic, once the global total processed in each step was known, hours worked, the calculation procedure of the relative parcel followed as described in equation 2, approximate values.

$$E_{ceq} = \frac{CDW_{pp} . C_{equip}}{CDW_{tp}} . Q \qquad (2)$$

where:

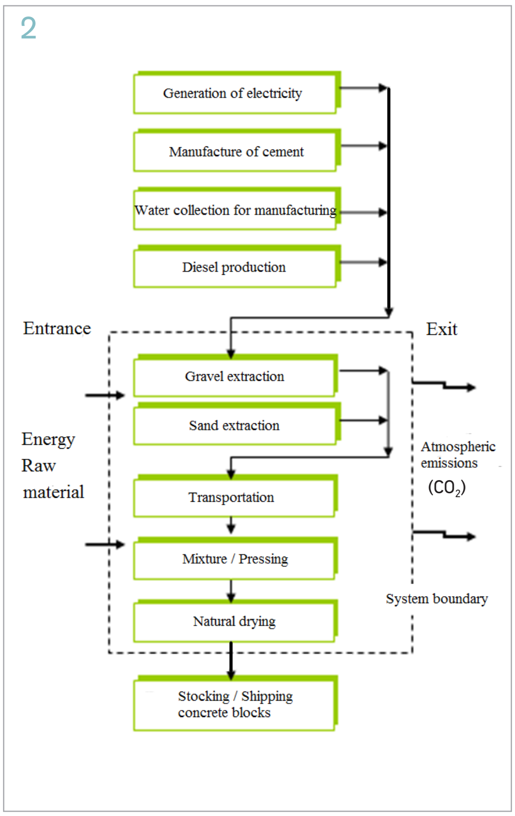
E_{ceq} – Energy consumed by equipment (kWh); RCD_{pp} – CDW of the processed proportion, the objective of the present study (kg); C_{equip} – Equipment consumption (kWh); RCD_{tp} – Total process CDW (kg); Q – Quantity of equipment (unit).

Concrete block raw material extraction

Sand is extracted using a dredge. For gravel, the aggregate is produced in a hard stone quarry and uses the following technology: development in banks, primary breaking, secondary breaking, loading of exploded mineral and internal transport. The flowchart (Fig. 6) was considered as basic support to define the boundary of gravel extraction, this is a first approximation.

Boundary study

These are the conditions needed to guarantee the study (Guine, 2002). If these limits aren't observed, the risk is run of adding complexity and costs to the system, which will make conclusion and technical analysis of the Life Cycle Assessment more difficult according to Ferreira (2004). The dotted line marks the limits of the system; the processes considered in the study are configured within this space, as illustrated in Fig. 2, 3, 4, 5 and 6.



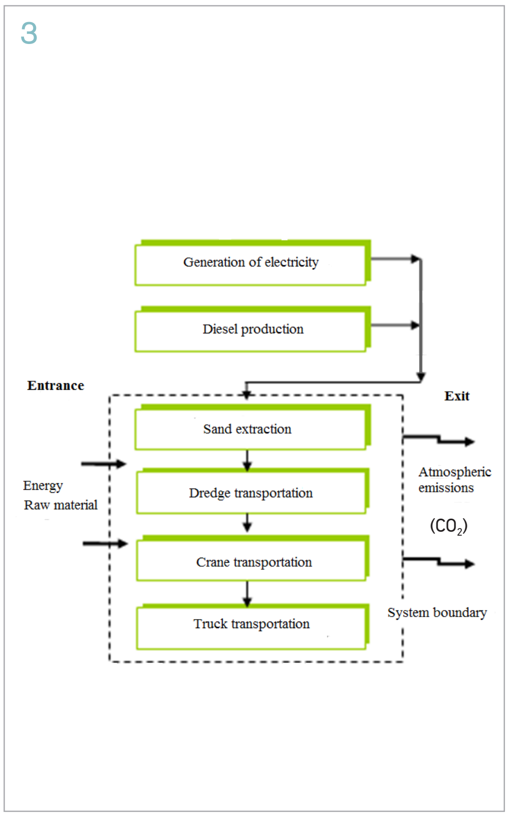


Fig. 2
Concrete block boundary

Fig. 3
Sand extraction boundary

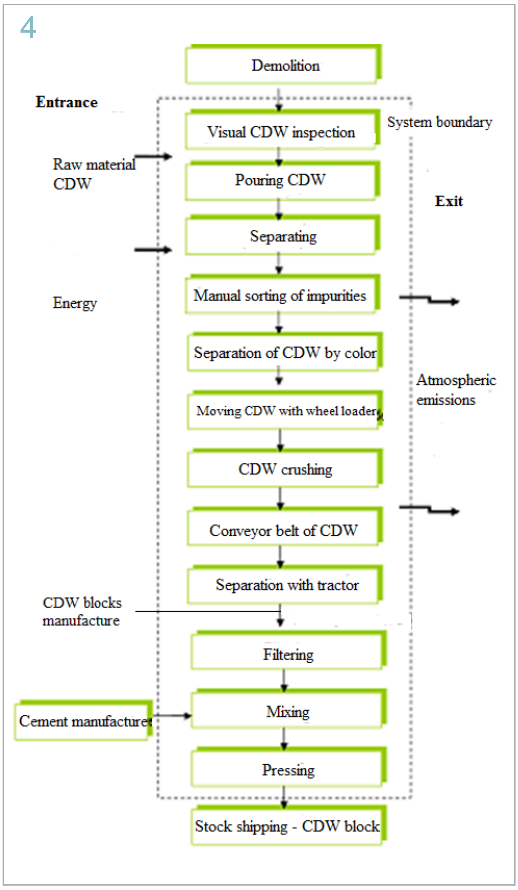


Fig. 4

Boundary of CDW block

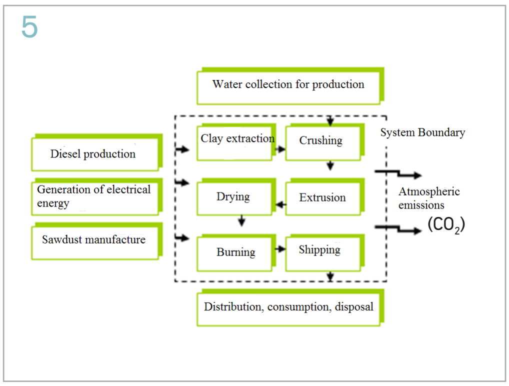


Fig.5

Boundary of ceramic brick (Soares & Pereira, 2004)

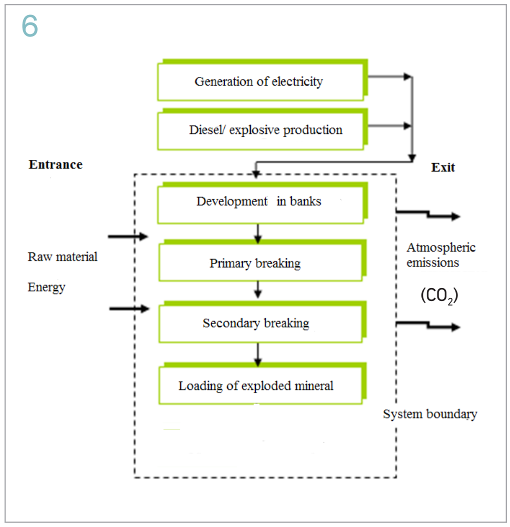


Fig. 6

Gravel extraction boundary

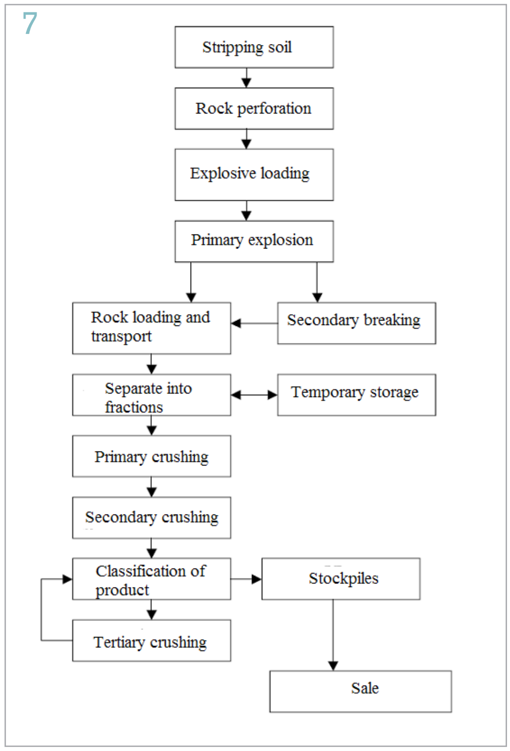


Fig. 7

General gravel extraction flowchart

Description of the block being studied

This study considered the following general characteristics for the blocks (Table 1). For the concrete blocks, the first estimate is as in Mastella (2002). For the CDW block the following table uses Santos (2007) and the ceramic brick is as in Soares & Pereira (2004).

Table 1

General characteristics adopted for the blocks.

Comparison	Material		
	Block - CDW	Block - Concrete	Brick - Ceramic
Functional unit	13.13 pc/m^2	16.67 pc/m^2	32.18 pc/m^2
Product unit	114.71 kg/m^2	155.86 kg/m^2	113.36 kg/m^2

CDW block

The processes from processing of rubble to production of the block were considered for CDW block. According to Angulo *et al* (2002), the variations of composition of CDW (mass) are generally estimated based on the material. From the same data, a composition estimate can be carried out in function of the materials present in the CDW in the study, such as cement, sand, lime and others as in Table 2.

Table 2

Estimate of the mineral portion of CDW in materials (Angulo *et al* 2002)

CDW (% mass)	Cement		Lime		Sand		Rocks		Ceramic	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Concrete [1]	3.3	10.3	-	-	6.7	20.7	10.0	31.0	-	-
Mortar [2]	0.7	4.2	0.8	4.6	8.5	52.2	-	-	-	-
Rocks	-	-	-	-	-	-	3.0	50.0	-	-
Ceramic	-	-	-	-	-	-	-	-	0.0	30.0
Total (%)	**4.0**	**14.5**	**0.8**	**4.6**	**15.3**	**72.8**	**13.0**	**50.0**	**0.0**	**30.0**

[1] mass adopted 1:2:3
[2] trace adopted at volume 1:2:9 and at mass 1:1, 1:12, 3

Once the estimate of materials present in the CDW block has been defined, the choice of block mass proceeds according to the data available in literature. CDW blocks have similar chemical composition, apparent specific mass and relative water absorption, as in Angulo (2002). As a consequence, in order to establish the mass value of CDW block, this study considered the results of laboratory tests carried out by Santos (2007); the value of its mass in kg was computed after drying in an oven without previous saturation.

Similarly, this work adopted 7.63 kg as the mass of a CDW block in order to carry out the first correlation of materials incorporated into the CDW blocks studied, based on the data in Table 2, the estimated mineral content of CDW was 14.5% cement, 2.7% lime, 43.7% sand, 26.4% rocks, and 12.7% ceramic, calculated with an estimated mass of 7.6 kg CDW/block, which resulted in the estimate of materials present in CDW block, in kg: cement (1.1); lime (0.2); sand (3.3); rock (2.0); ceramic (1.0).

The estimate of water consumption for CDW block production is as in Santos (2007). It follows that for the equivalent of 400 kg CDW, 54 liters of water were added to make the CDW blocks. Thus approximately 0.14 liters of water are consumed per kilogram of CDW. So, for a mass of 7.6 kg equivalent to one CDW block, estimated consumption was 1.07 liters/block. Thus for 1.0 m^2, estimated consumption of potable water is 14.05 kg/m^2.

For the data referring to cement needed to produce CDW block, the study by Stachera Junior (2006) is considered. This study utilized apparent specific mass 1200 kg/m3, concentration of materials was 14% blast furnace slag, 10% calcium carbonate, and 3% plaster. Mehta & Monteiro (1998) mentioned that 73% of the composition of cement is clinker and that in this percentage are included 54.75% lime, 14.6% clay and 3.65% iron ore. However, note that to produce 1 m^2 of CDW blocks, the CDW had to be processed in a factory. This required around 49,066 KJ of energy to run the system. CDW volume considered was 5,621.7 kg CDW/m^2 to manufacture 1m^2 of CDW blocks.

Concrete block

The following input materials were registered, as in Mastella (2002): 16.9 kg/m^2 cement; 54.60 kg/m^2 gravel; 85.20 kg/m^2 sand; 2.95 kWh/m^2 electricy; 3.3 kg/m^2 water. According to Mastella (2002), the output data were: 0.03 kg/m^2 gas emissions; 4.67 kg/m^2 solid waste; 2.95 kWh/m^2 electricity. In order to refine the output values, the following data was incorporated considering proportions of 16.9 kg/m^2 cement, adopted according to Stachera Junior (2006); Metha & Monteiro (1994) gave the following basic composition: 14% blast furnace slag, 10% de calcium carbonate, 3% plaster and 73% clinkeer (54.7% limestone; 14.6% clay; 3.65% iron ore). Thus the input data for cement were: 2.37 kg blast furnace slag; 1.69 kg calcium carbonate; 0.51 kg plaster; 2.47 kg clay; 0.62 kg iron ore; 11.83 kWh/m^2 thermal energy; 1.69 kWh/m^2 electricity. The energy data are based on Hernandes & Kaminski (2004), who considered 700 kcal/t of cement for thermal energy and 100 kWh/t of electricity. The first estimate in order to register output data was: 8.45 kg CO_2; 0.05 kg NOx; 0.02 kg SO_2; 0.01 kg MP.

To manufacture concrete block, the data input was the following: 85.6 kg/m^2, considering the unit mass of 1.43 kg/dm^3. It is known that 1 dm^3 equals 10^{-3} m^3. Thus, 1.43 kg/m^2 is equivalent to 0.001 m^3, and from this it can be concluded that 85.20 kg equals 0.06 m^3/m^2. For dredge extraction, according to Cybis & Santos (2000), 100 m^3 capacity was considered with a 120 km path and 1 km/liter of diesel. For a 40 km highway trip with a 4000 kg capacity truck with 3 km/liter fuel consumption, estimated fuel consumption was 13.3 liters, rounded up to 14 liters. Thus diesel consumption for transportation was 0.29 liters of diesel/m^2.

Crane capacity adopted was 12000 kg with fuel consumption of 18 liters/hour of diesel oil. 12000 kg is equal to 18 liters, thus 85.2 kg results in 0.13 liters of diesel/m^2. Following the same logic, 100 m^3 equals 120 liters for the dredge, thus 0.06 m^3 results in 0.07 liters of diesel/m^2. Thus the consumption considered was 0.49 liters of diesel/m^2. Diesel density adopted in this study was 0.86 kg/liter, as in Stachera Junior (2006). For data output, the following estimated emissions values were found: 1.37 kg CO_2; 0.03 kg CO; 0.09 kg CH_4; 0.04 kg NOx; 0.11 g N_2O and 1.55 g NMVOC.

For clay extraction, 54.6 kg/m^2 consumption was considered. The unit mass adopted was 1.35 g/cm^3. Thus, if 1.35 g is used in 1 cm^3, 54,600 g result in 0.04 m^3/m^2. According to Piquet (2006), the steps considered for aggregate production in a hard stone quarry were obtained utilizing the following technology: step removal; primary breaking; secondary breaking; exploded material loading; internal transport. To operate the mine, the data input considered are the following: primary drilling with a 200 hp electric compressor consuming 0.38 kWh/t. Primary explosion and secondary breaking with a 1200 kg jackhammer coupled to a 20 t hydraulic excavator hydraulic (140 hp diesel motor) consuming 0.07 liter/t diesel consumption. Loading with a 35 t hydraulic excavator (250 hp diesel motor) with a 2.4 m3 bucket fixed to a rear arm; a mechanical wheeled-shovel-type auxiliary machine with a 3m3 bucket and 200 hp diesel motor; estimated consumption was 0.16 l/t. Internal transportation used a 30t off-road truck with a 7-minute cycle time and hourly production of 216t per truck; thus the calculated fuel consumption was 0.08 l/t as in Piquet (2006).

Ceramic brick

The following input data was used for ceramic brick: 130.26 kg clay, 0.26 kg water, 31.11 kg saw dust, 0.06 kg diesel oil and 0.3 kW electricity. Output data were: 53.58 kg evaporated water, 41.88 kg carbon dioxide, 0.02 kg nitrogen dioxide, 0.5 kg carbon monoxide, 1.56 kg solid waste, with 93.7 kg of final product (Soares & Pereira, 2004).

Flow network scenarios in Umberto software

From the data presented, a flow network was put together using Umberto software for ceramic brick and cement block. The network developed was compact because a detailed system doesn't have to be developed in order to use the Umberto program. The detailing resource proceeds when the analysis of improvements for the environment and the interdependence between the processes in a production line are planned (Mondardo Filho & Muller-Beischimidt, 2004). For CDW block, the network was developed from the arrival of CDW at the plant through manufacture of CDW block.

The material components of the life cycles of the agents involved in this study were input into Umberto software, defining the unit for each type of material separated into groups (work folders in Umberto). These work folders were created for energy, emissions, raw materials, supply and other items. Then this study's flow networks are presented. Three different scenarios were created: the ceramic brick manufacturing scenario (**Fig. 7**); the concrete block manufacturing scenario (**Fig. 8**); and the CDW block manufacturing scenario (**Fig. 9**), this is a first approximation.

CDW processing, CDW block manufacturing, ceramic brick manufacturing and concrete block generating inventories were generated from these scenarios. For easier visualization, the Sankey

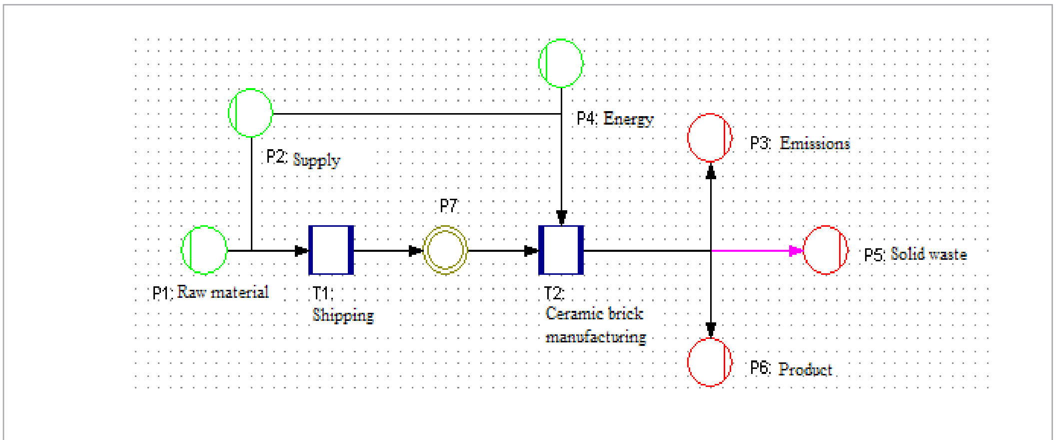


Fig. 7

Ceramic brick manufacturing scenario

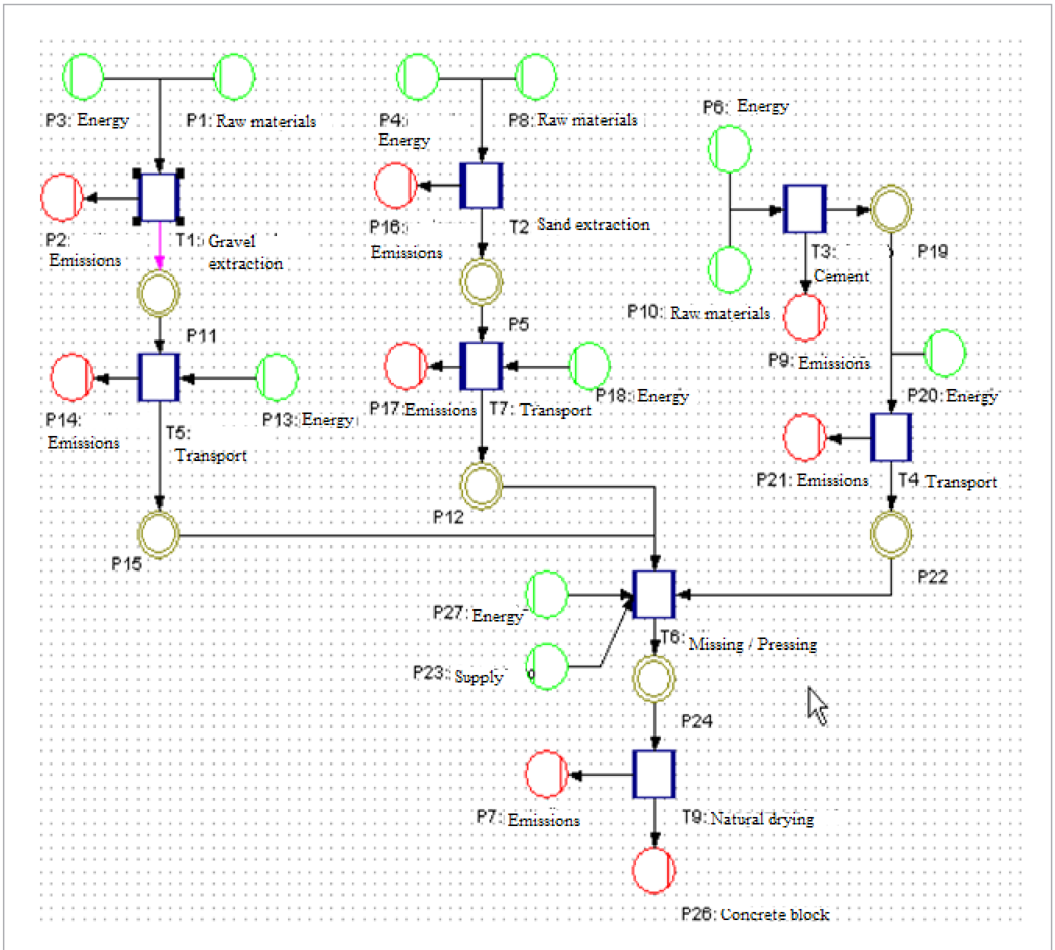


Fig. 8

Concrete block manufacturing scenario

Fig. 9

Processing/manufacturing of CDW block scenario

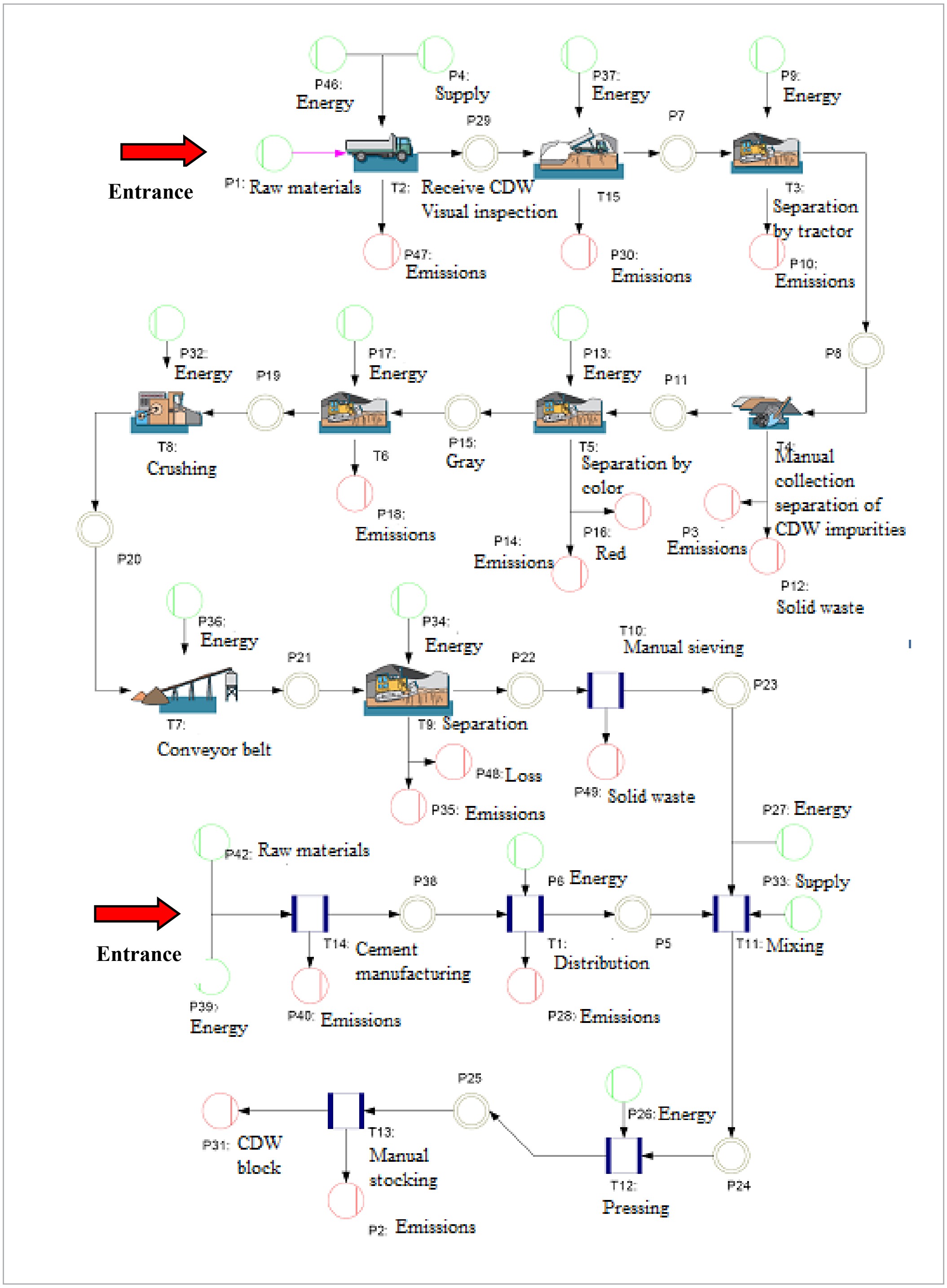


diagram is utilized as a card representing material flow. The flow quantities are shown by arrows with width proportional to mass or energy, this is being a first analysis.

Sankey diagrams for concrete block

The Sankey diagram illustrates the great concentration of CDW material in the first phases of CDW processing. This occurs largely due to the type of processing employed by the plant in separating material in restricting the manufacturing area to semi-handmade CDW block manufacturing technology and the use of CDW for purposes other than that analyzed in this study, identified in process T5, separation by color (Fig. 10). CO_2 emissions result in a carbon footprint of approximately 29 kg/m² CO_2, the equivalent of 44.46% o the emissions considered. For the critical energy flow, this occurs at T14, cement manufacture, with 42,154 KJ/m², the sum of electrical and thermal energy expended.

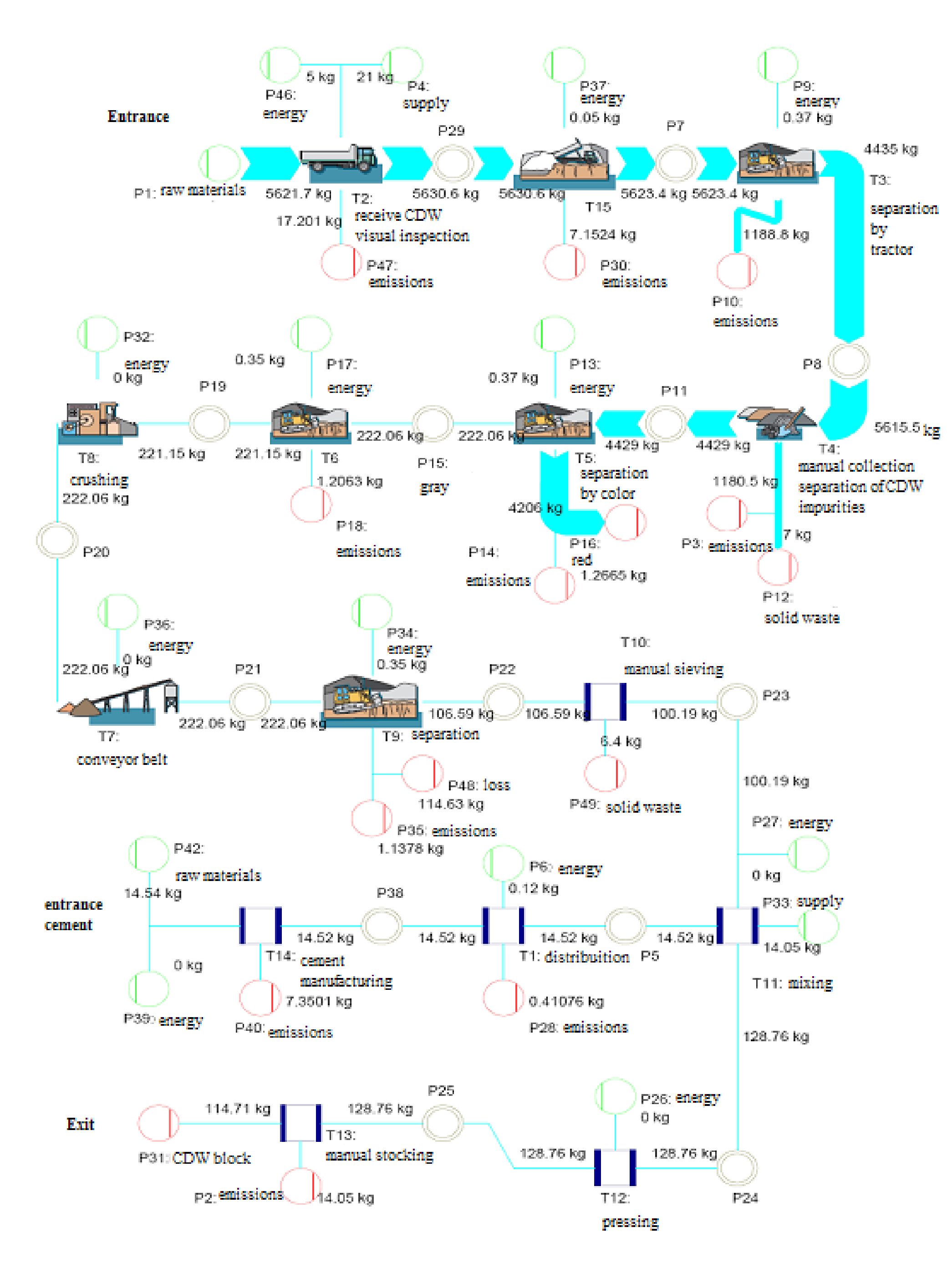


Fig. 10

Material – processing flow Sankey diagram for CDW and CDW block manufacturing

Sankey diagrams for ceramic brick

In the Sankey diagram, note that in block manufacture, the critical energy flow is located in electrical energy consumption, with 1080 kJ/m^2 (Fig. 11). A stretch of the critical mass flow occurs in natural resource extraction for clay, with a total estimate of 159.86 kg/m^2 of ceramic brick up to transition T1 (Shipping) (Fig. 11). The other stretch that also illustrates critical flow occurs between T1 and T2 (block manufacturing) with 161.37 kg/m^2, which reflects the sum of the mass of the previous stretch, from extraction up to T1, plus 31.11 kg/m^2 from sawdust supply (Fig. 12). For the objective drawn, the quantification of carbon footprint, there is a predominance of 41.88 kg of CO_2 emissions/m^2, or values around 42 kg of CO_2 emissions/m^2.

Fig. 11

Sankey graph for energy, ceramic brick

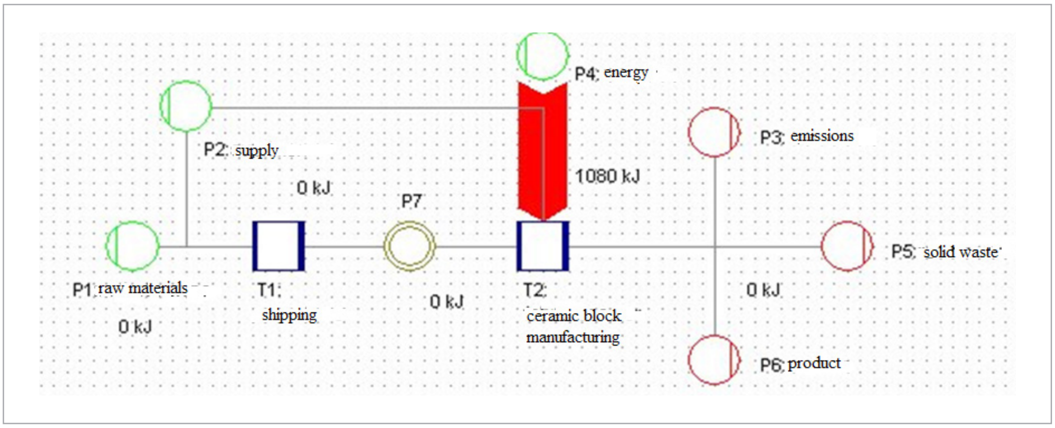
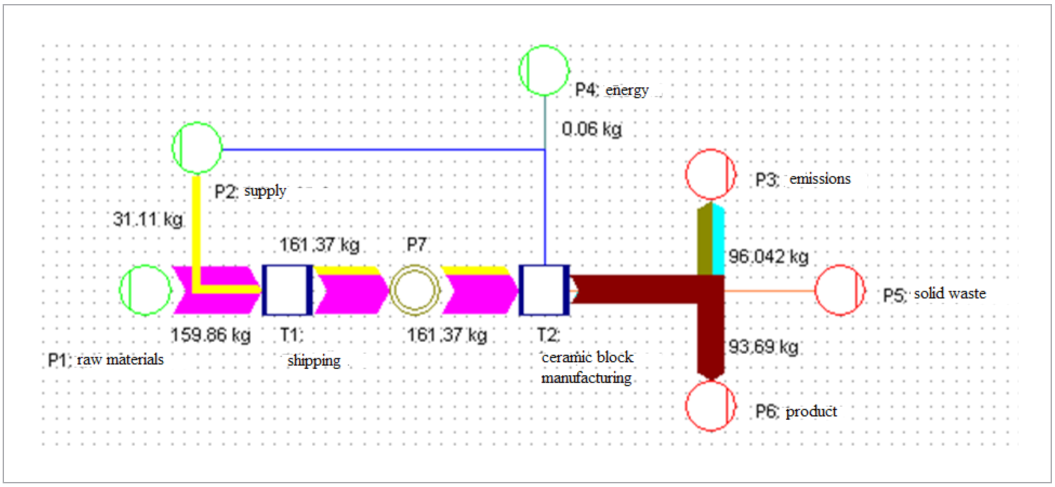


Fig. 12

Sankey graph for mass, ceramic brick



Sankey diagram for concrete block

From the Sankey diagram, note the critical energy flow (Fig. 13) is located in cement production with 48,672 kJ, followed by mixing and pressing with 10,620 kJ. In terms of percentage, the average measurement is 28.33% electrical energy and 71.67% thermal energy.

For critical raw material flow (Fig. 14), process T6, mixing, stands out. Thus special attention should be given to this step of the process since remedial measures relating to the type of equipment to use are welcome for the purpose of future proposals to improve the process and optimize production, which aren't the objective of this article.

For emissions, note the critical flow occurring at process T3, cement fabrication, followed by process T5, transportation, with approximately 2.07 kg/m^2 atmospheric emissions.

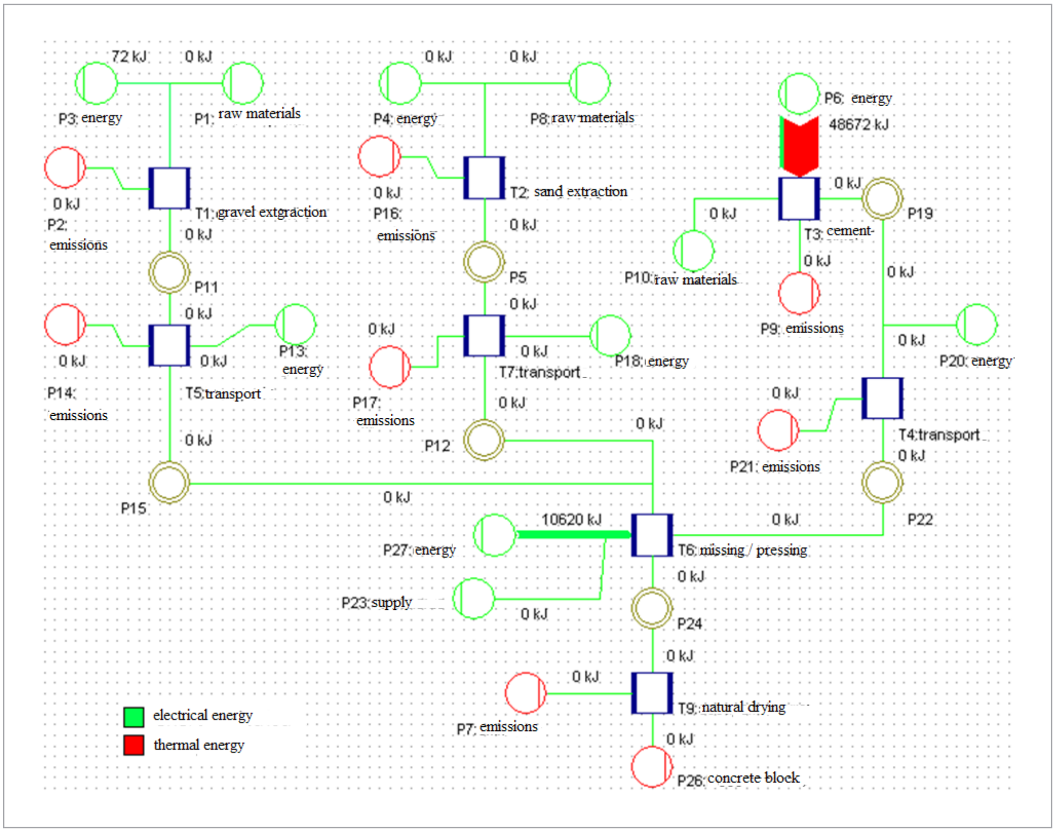


Fig. 13

Sankey graph for energy, concrete block

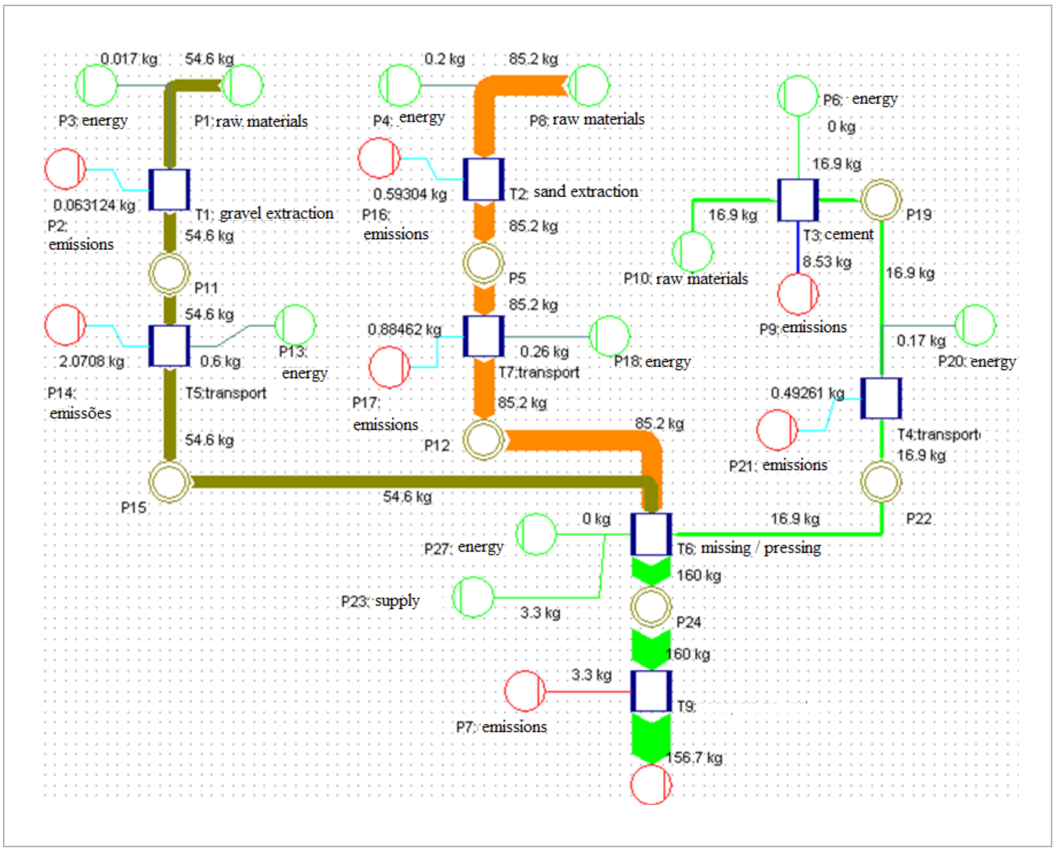


Fig. 14

Sankey graph for mass, concrete block

Comparison of "carbon footprint"

From the comparison between inventories generated in the Umberto software, it can be verified that ceramic brick has the highest level of CO_2 emissions, with 42 kg/m^2, followed by CDW block, with 28 kg/m^2 and concrete block with 12 kg/m^2 of emissions. Therefore, concrete block remains the material with less environmental impact in terms of CO_2 emissions. This study corroborates with Mastella (2002) in the statement that concrete block has less environmental impact. It agrees with the study of Koroneos & Dompros (2006), who also deal with ceramic brick manufacture, and attribute high environmental impact from CO_2 emissions of production of this material. Although carbon footprint is a reality in the decision making process for construction materials for countries in the northern hemisphere, the fact that the raw material for manufacture of these blocks is non-renewable must be repeated. Uncontrolled extraction also has other environmental impacts and large-scale losses for the human being of future generations.

For the manufacturing process of CDW blocks, note that in the steps where fossil fuel is used, it was responsible for increasing the CO_2 emissions indices, and thus one alternative would be to substitute this fossil fuel for another of vegetable origin and thereby obtain another advantage for a CDW recycling program in Brazil (Biodiesel Brazil, 2009).

The analysis made it possible to verify a substantial improvement in the rubble separation step, since this had a high critical flow in the first work steps of the recycling plant. For example, adding a dense liquid separation process to the facility would add value to the final product of the plant. Note that the index of impurities present in the CDW reception process is much higher than is allowed (10% impurities) by the Secretary of Urban Hygiene of Belo Horizonte, MG. The level of impurities found in this study was 21.34% of the total 5,621.7 kg CDW/m^2.

Also add to that the fact that separating CDW at the point of origin would significantly contribute to improving the final recycling process as well as recovering around 10% of the impurities permitted in receiving CDW on the part of the processing plant. The measure of source separation substantiates Agopyan's recommendations (2001). Another way to diminish the negative load incorporated into CDW block would be substituting Portland cement agglomerate for another with less environmental impact, according to Vlasopoulos (2008). Thus adopting mitigating measures for the recycled product analyzed could allow it to reach higher quality levels and let it compete more equally in terms of CO_2 emissions with the manufacture of concrete block, in addition to not requiring raw material extraction.

Conclusions

In this first approach to the production of the CDW block considered the industrial reality of Estoril plant in the city of Belo Horizonte, in Minas Gerais, Brazil, in 2008. Of this total received from CDW found the need of approximately 5621 kg of WC&D to produce 1 m^2 of CDW blocks or equivalent to 114.71 kg/m^2 blocks. The *Sankey* diagram (Fig. 10) shows a large concentration of material, "CDW" in the early stages of processing these Wastes. That overall amount disregarded is the reddish colored residue and only tapped the gray colored residue for the manufacture of this block. However, only 222.06 kg were effectively used in the manufacture of the residue block. The remaining 4206 kg it is the red colored residue, which is directed to other uses purposes not in the present study. Even as this red residue is not used for block manufacturing study.

This was largely due to the process of segregation of the material from the plant, the narrow semi-artisanal manufacturing plant manufacturing block with CDW, and the destination of this waste for purposes other than the subject of this study, identified in T5 process - separation by color (Fig. 10).

As for CO_2 emissions, it is resulted in a "carbon footprint" of approximately 29 kg/m^2 of CO_2, equivalent to approximately 44.46% of emissions considered in this study (Surgelas, 2010).

As the comparison of CO_2 emissions for block and brick manufacturing (Fig. 13). Obtained as a “carbon footprint” reduced to the concrete block (12 kg/m^2 CO_2) in relation to the other CDW blocks of 28 kg/m^2 of CO_2 and the ceramic block 42 kg/m^2 CO_2. In that stage, this proved to be more advantageous to the extraction of raw materials directly from nature, for the manufacture of concrete block, because of its manufacturing process. This concrete block resulted in better performance in relation to other blocks analyzed.

However, when opting for improvement in the processes used in the production of other CDW and ceramic blocks can reverse this situation, and from that obtain satisfactory results, or perhaps even reverse the final result. But for this to occur, interference and improvements in the production process

The results obtained in this work, they can be used for strategic purposes, product information, and the operational level, tactical and managerial / strategic, as Ferreira (2004). Regarding the type of audience that is intended to give partial results are the technical meetings, technical journals, conferences, journals, among others related to the gym. Among the target audience are involved in decision making, engineers, architects, administrators, researchers from engineering, environment, climate area, management, management, cleaner production, among other researchers

Finally, these results could be useful in identifying and developing alternative technology with a low environmental impact, as well as the detailed analysis of the essential phases of each alternative. What would occur to a more sustainable clean production, socially, environmentally and economically more viable. This is a first approximation.

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