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Building life cycle energy assessment on pre operation phase using BIM

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ABSTRACT: Life Cycle Assessment (LCA) is a very important tool for several analyses and it is used to quantify environmental impacts related to products or services. It is essential that building LCA be done during pre-design stage, in order to avoid impacts caused by material waste and lack of planning. Life Cycle Energy Assessment is a LCA method, which analyze energy consumption impacts. Building energy life cycle can be divided into pre operation phase, operation phase and post operation phase. This paper presents a methodology to calculate building embodied energy for pre operation phase during the design stage, using the software Revit Architecture to improve material selection processes. Building Information Modeling (BIM) aims to reduce rework, to properly manage projects information, to model and simulate building performance through temporal, economic and sustainable perspective. The proposed methodology has proved as a feasible and practical tool, since it easily provides results about embodied energy, once materials and model settings are defined.

Keywords *Life Cycle Energy Assessment. Embodied Energy. Building Information Modeling.*

1. INTRODUCTION

Despite the importance of environmental concerns, buildings performances has been measured traditionally in terms of quality, time and money. Environmental performances analysis are relatively new, therefore it presents great methodological challenges, which limits its practicality and reliability (Saade, 2014). Construction is regarded to be the industry with less investment in research and development. This fact naturally hinders any improvement and technological developments. Small and medium sized companies are the majority in construction industry, while large companies are those with most resources for research. Temporary alliances on individual projects is also an aspect that delays the application of new methods of design and construction (Antón & Díaz, 2014). This paper aims to propose a Life Cycle Energy Assessment methodology on buildings pre-operation phase, applied to a residential housing in Brazil. This methodology uses the Revit Architecture software to quantify embodied energy values in selected construction materials during the design stage and project.

2. LIFE CYCLE ASSESSMENT

Through building Life Cycle Assessment (LCA), businesses, governments and organizations are able to identify opportunities, to plan and establish better strategies for construction industry. Thus, it becomes feasible the improvement of environmental construction aspects, allowing proper selection of material and suppliers (Silva, 2012). From environmental perspective, LCA provides a complete inventory of mass and energy flows for each system, and it allows that appraisal about generated impacts to be compared (Bueno et al., 2013).

Life Cycle Energy Assessment (LCEA) is a simplified but relevant way to evaluate environmental impacts. This analysis is based on ISO 14040 standard (ISO, 2006), and it is performed by energy consumptions inventory data of direct and indirect processes. Through LCEA it is also possible to identify environmental impacts, and since it has more simplified structure than a complete LCA, it demands lower cost and less effort (Tavares, 2006). According to Bueno et. at. (2010), building life cycle includes: construction materials fabricating, building construction itself, operation and maintenance, disassembly or deconstruction and waste management phases. All stages should be considered in a full LCA, i.e. all processes from "cradle to grave".

Initial Embodied Energy (EE) is defined as a sum of all energy inputs required to extract raw materials, to processing, manufacturing and transporting products and materials that will be used in construction, including transportations to construction site, and all energy spent in construction processes itself. Besides EE, there is also a large energy consumption from home appliances and several devices used during the whole building life, called operational energy. This operational energy includes all energy demand with lighting, cooking, entertainment, climate control, and numerous activities. The post-operational phase of building life cycle begins when building is considered as non-suitable for proper use and performance, and in that moment it starts the deconstruction processes. The energy consumption during this phase comes from machines used in demolition or deconstruction processes, also due to waste transportation to its final disposal site, or in reuse and recycling procedures (Tavares, 2006).

3. BUILDING INFORMATION MODELING

Building Information Modeling (BIM) is one of the most promising progress on Architecture, Engineering and Construction (AEC) industry. With BIM it is possible to create building virtual models accurately. Once these models are finished, they contains precise geometries and significant data representing project's information that can help construction, manufacturing, products purchase and analyses. BIM also provides many essential functions for modeling wholly building life cycle, giving possibilities for new and most appropriate designs and projects improvement. When BIM systems are correctly implemented, it easily provides more integrated projects and processes, which results in better constructions with ideal quality on low costs and reduced project time (Eastman et al., 2011).

BIM is a technique that uses 3D models together with intelligent tools, for example, using information about schedules and timelines (4D), or cost-related and financial aspects (5D). About the sixth BIM dimension, there is not a very well defined concept among authors and researches yet, but it is possible to affirm that the term BIM 6D consists in building life cycle analyses, related to performance, maintaining and sustainability (Yung & Wang, 2014).

Environmental friendly services requires collaborative tools support and BIM can contribute for communication and collaboration improvement between different actors involved in a project. There is an advantageous synergy between BIM and sustainable constructions since BIM offers integrated model, global view and it provides facilities at projects. BIM systems provides means to information flows in order to increase quality and performance. Supporting collaborative working for all people involved in a project, during the design stage, could avoid future mistakes, costs and unnecessary reworks. BIM models provides structured data that also could be very useful in industrialization processes, as pre-fabricated constructions (Antón & Díaz, 2014).

4. METODOLOGY

The proposed methodology could be defined as a simplified Life Cycle Energy Assessment that considerate only pre-operation phase inside the system. That is, operation phase and post operation phase are not included on the method developed. It was used the Revit Architecture 2014 software to test this methodology, and thus it was possible to create a simple residence model as an example. It is a nonexistent house, created just as a sample that has one bedroom, one bathroom, a dining/living room and a kitchen. The total area is 106 $m^{2,}$ and its floor plan is presented in Figure 1. Once consumption energy in operation phase will not be estimated in this paper, than the amount residents, its consumption pattern and types of devices in the house were not defined. Only building systems and materials components are specified in here.

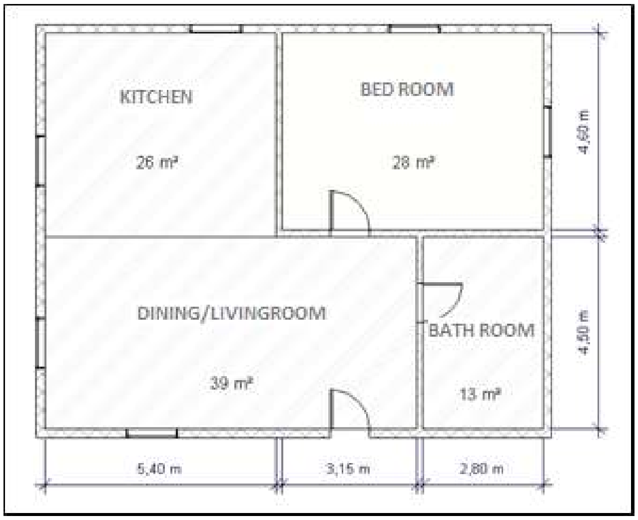


Figure 1. House floor plan modeled as example

4.1 Creating elements and specifying materials

Materials specifications used at the test model are listed at Table 1. It is essential to emphasize that the produced model aims to experiment the practical application of energy LCA methodology only, and not to judge construction systems, performances or materials as appropriated or not.

Table 1. Description of elements and materials defined on the model

Elements	Description of materials
Walls	Brick with concrete in internal and external layers
Floor	Floating wood tile on bedroom and ceramic tile in the rest
Ceiling	Gypsum board on all rooms
Slab	Concrete
Roof	Red ceramic roof tile
Doors	Planed wood
Windows	Glass and wood

Each building element used on the project was created with desired specifications. Revit has already several construction components registered in its library, such as walls, doors, windows, plumbing, etc. Components are separated into Families, which are subdivided into subcategories and then into Types. Each Type is a specific element that has an individual function and it has special characteristics defining materials, thicknesses, physical and mechanical proprieties, appearances, shapes and varied parameters.

It is possible to insert new elements that are not registered in Revit libraries, therefore, new elements types were created according to chosen specifications. Elements Type had its structures, materials, layers, finishing and parameters detailed in Revit. And for each material inserted in a new element, also it is possible to edit features as the name, composition, colors, physical and thermal proprieties. This procedure was done for each element in BIM model. It is possible also to save the created Families, so then, new elements could be used in others and future projects.

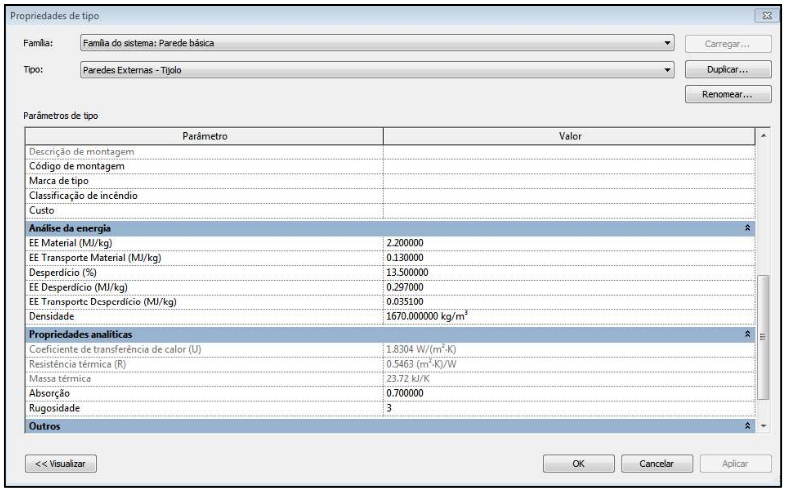
4.2 Inserting energy parameters

The next step performed was to determine Embodied Energy (EE) of all elements. At “Manage” tab the option “Shared Parameters” was selected in order to create new parameters, which could be used on several Families. All Shared Parameters created are listed on Table 2.

Table 2. List of parameters inserted in Revit and theirs adopted symbols

Description	Parameters name assigned in Revit	Symbols used in equations
Density	Density (kg/m³)	d
Materials Embodied Energy	EE Material (MJ/kg);	EE
Wastage rate	Wastage (%)	w
Embodied Energy in material wastage	EE Wastage (MJ/kg);	EE_w
Energy consumption in material transportation	EE Material Transportation(MJ/kg);	EE_t
Energy consumption in material wastage transportation	EE Wastage Transportation (MJ/kg),	EE_{wt}

Once the new Shared Parameters were completed, it was necessary to create “Type Parameters”, which specify parameters that could be added in elements categories of a model and then, it could be used and showed in tables. Numeric values can be attributed on Type Parameters, and these numbers will appear in all parameters of all same elements type automatically. For example, for all floors that was defined as “Floor Type 1”, parameters of EE would have the same value on BIM model. Figure 2 presents an image of parameters showed in type proprieties window.



Família: Família do sistema: Parede básica
Tipo: Paredes Externas - Tijolo

Parâmetros de tipo

Parâmetro	Valor
Descrição de montagem	
Código de montagem	
Marca de tipo	
Classificação de incêndio	
Custo	
Análise da energia	
EE Material (MJ/kg)	2.200000
EE Transporte Material (MJ/kg)	0.130000
Desperdício (%)	13.500000
EE Desperdício (MJ/kg)	0.297000
EE Transporte Desperdício (MJ/kg)	0.035100
Densidade	1670.000000 kg/m³
Propriedades analíticas	
Coeficiente de transferência de calor (U)	1.8304 W/(m²·K)
Resistência térmica (R)	0.5463 (m²·K)/W
Massa térmica	23.72 kJ/K
Absorção	0.700000
Rugosidade	3
Outros	

Figure 2. New parameters in Type properties window

4.3 Attributing and calculating energy parameters values

It was used values determined by Tavares (2006) to attribute energy values in each element. As done in Araujo (2015) method, for those elements that have more than one material in its composition, such as walls with various layers, doors and windows, the values of energy parameters was calculated based on material proportion related at total volume and their densities. The next example presents how parameters of internal walls were calculated. These walls were created on software as composed by with 9.0 cm brick thickness and 3.0 cm of concrete on both side representing mortar and plaster. The total sum results wall thickness of 15.0 cm. Table 3 presents density and embodied energy values for each materials and theirs wastage rate, using as example the Internal Wall Type.

Table 3. Energy values assigned for materials used on Internal Wall Type

Material	EE_{brick}	$EE1_{brick}$	w	d
	MJ/kg	MJ/m³	%	kg/ m³
Brick	2.90	4060.00	15	1400.00
Concrete	1.20	2760.00	10	2300.00

Equations 1 and 2 are used to calculate brick and concrete proportions at 1 meter of wall:

$$P_{brick} = e_{brick} / e_{wall} \tag{1}$$

$$P_{conc.} = e_{conc.} / e_{wall} \tag{2}$$

where *e* is thickness and *P* is proportion of each wall material. The proportion founded is 0.60 of brick and 0.40 of concrete. The Equation 3 are used to calculate the wall density in kg/ m³

$$P_{brick} \times d_{brick} + P_{conc.} \times d_{conc.} = d_{wall} \tag{3}$$

$$0.60 \times 1400 + 0.40 \times 2300 = 1760.00$$

Calculus of internal wall energy embodied is presented on Equation 4 in MJ/ m³ and in MJ/kg on Equation 5. Equation 6 represents calculus of wastage rate (*w)* in percentage.

$$P_{brick} \times EE1_{brick} + P_{conc.} \times EE1_{conc.} = EE1_{wall} \tag{4}$$

$$0.60 \times 4060 + 0.40 \times 2760 = 3540.00$$

$$EE1_{wall} \div d_{wall} = EE_{wall} \tag{5}$$

$$3540 \div 1760.00 = 2.01$$

$$P_{brick} \times w_{brick} + P_{conc} \times w_{conc} = w_{wall} \tag{6}$$

$$0.60 \times 15.0 + 0.40 \times 10.0 = 13.00$$

The embodied energy value of material wastage is equal to EE multiplied by its wastage rate.

$$EE_{w} = EE \times w \div 100 \tag{7}$$

To estimate energy consumption for materials transportation, distances from factories to construction site were not considerate, since the project is a nonexistent house. So it was attributed 80.0 km as a default distance, as Tavares (2006) method. The distance is applied at energy consumption index for diesel vehicles, 1.62 MJ/t/km, resulting in 0.13 MJ/kg. That index was considerate for all materials transportation in this paper. Material wastages need double transportation distance, since it comes and go to construction site, then, in these cases, transportation index is 0.26 MJ/kg.

$$EE_{wt} = 0.26 \times w \div 100 \qquad (8)$$

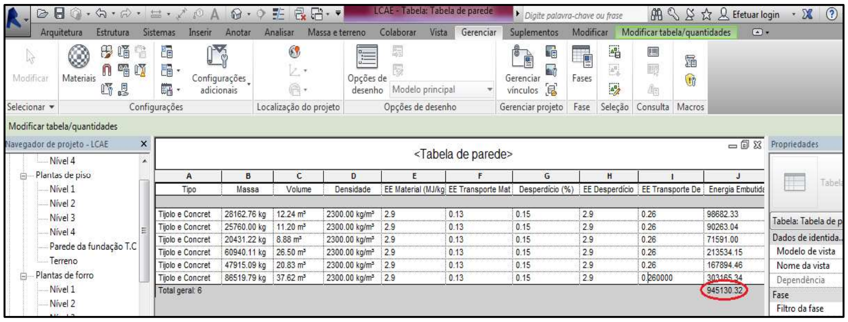
Same calculus procedure and equations were used for all others buildings elements. It was not considerate on BIM model any foundation, structural, mechanical, electrical and hydraulic components, such as plumbing, column, beam, etc. Once model was created to test the methodology only, projects were simplified in this study. However, for another elements, values entry way and parameters calculus should be done with same processes described.

4.4 Creating tables

After parameters insertion and calculation for all elements on the model, it was created tables by tools available in Revit to quantify and to sum values of energy embodied. One table for each Family were created, specifying previous existent parameters and the new ones related with EE. In the end is possible to add more columns on tables and insert equations and formulas in it in order to perform operations with table values. So, one more column was added to multiply volume column to the densities one and resulting in a Mass elements parameter, in kilogram unit.

Lastly, other column was added to calculate the Total Energy Embodied, which is the sum of all four energy parameters created (item 4.2), multiplied to elements mass, according Equation 9. It is possible to generate the sum of all total energy embodied, as displayed in Figure 3, that present an example of created table.

$$EE_{Total} = Mass \times (EE + EE_t + EE_w + EE_{wt}) \qquad (9)$$



<Tabela de parede>

A	B	C	D	E	F	G	H	I	J
Tipo	Massa	Volume	Densidade	EE Material (MJ/kg	EE Transporte Mat	Desperdício (%)	EE Desperdício	EE Transporte De	Energia Embutida
Tijolo e Concret	28162.76 kg	12.24 m³	2300.00 kg/m³	2.9	0.13	0.15	2.9	0.26	98682.33
Tijolo e Concret	25760.00 kg	11.20 m³	2300.00 kg/m³	2.9	0.13	0.15	2.9	0.26	90263.04
Tijolo e Concret	20431.22 kg	8.88 m³	2300.00 kg/m³	2.9	0.13	0.15	2.9	0.26	71591.00
Tijolo e Concret	60940.11 kg	26.50 m³	2300.00 kg/m³	2.9	0.13	0.15	2.9	0.26	213534.15
Tijolo e Concret	47915.09 kg	20.83 m³	2300.00 kg/m³	2.9	0.13	0.15	2.9	0.26	167894.46
Tijolo e Concret	86519.79 kg	37.62 m³	2300.00 kg/m³	2.9	0.13	0.15	2.9	0.260000	303165.34
Total geral: 6									945130.32

Figure 3. Example of table created for generating result of total EE

5. RESULTS

Through the Life Cycle Energy Assessment methodology proposed in this paper, it was possible to generate several tables, one for each Family category , in which are specified elements Types, parameters values and the sum of all energies embodied calculated. Total of seven tables were created, one for each Family, that is: ceiling, window, door, floor, roof, slab and wall. The software does not allow to insert all data at same table, if it would, probably the sum of all energy values would be simpler. Therefore, energy embodied values for each families needed to be sum separately before find the final result. However, it is allowed to export table as text file (.txt) and then, it is possible to work the results in several ways, including as spreadsheets.

On Table 4 are detailed all entry parameters values, mass and EE values calculated.

Table 4. Results generated in Revit tables

Type	Mass	EE Material	EE Material Transportation	EE Material Wastage	EE Wastage Transportation	EE Total
		(MJ/kg)	(MJ/kg)	(MJ/kg)	(MJ/kg)	(MJ)
Gypsum board ceiling	370.39	6.10	0.13	0.00	0.00	2307.54
Gypsum board ceiling	855.36	6.10	0.13	0.00	0.00	5328.89
Gypsum board ceiling	166.32	6.10	0.13	0.00	0.00	1036.17
Bat room window	9.30	15.60	0.13	0.39	0.01	149.95
Bathroom window	9.30	15.60	0.13	0.39	0.01	149.95
Generic window	1.82	16.72	0.13	0.53	0.01	31.58
Generic window	1.82	16.72	0.13	0.53	0.01	31.58
Generic window	1.82	16.72	0.13	0.53	0.01	31.58
Generic window	1.82	16.72	0.13	0.53	0.01	31.58
Generic window	1.82	16.72	0.13	0.53	0.01	31.58
Generic window	1.82	16.72	0.13	0.53	0.01	31.58
External Wall	9109.02	2.20	0.13	0.30	0.04	24,249.11
External Wall	11,350.16	2.20	0.13	0.30	0.04	30,215.25
External Wall	9266.00	2.20	0.13	0.30	0.04	24,667.01
External Wall	100,606.40	2.20	0.13	0.30	0.04	28,235.30
Internal Wall	3703.92	2.01	0.13	0.26	0.03	9025.28
Internal Wall	4517.01	2.01	0.13	0.26	0.03	11,006.52
Internal Wall s	3107.91	2.01	0.13	0.26	0.03	7572.99
Ceramic floor tile	3888.00	5.00	0.13	0.00	0.00	19,945.44
Ceramic floor tile	756.00	5.00	0.13	0.00	0.00	3878.28
Floating wood tile	547.17	7.50	0.13	1.13	0.04	4811.81
Wood door.	57.92	3.50	0.13	0.00	0.00	210.23
Wood door.	57.92	3.50	0.13	0.00	0.00	210.23
Wood door.	57.92	3.50	0.13	0.00	0.00	210.23
Red ceramic roof tile	5813.58	5.40	0.13	0.00	0.00	32,149.08
Slab	13,372.49	1.20	0.13	0.12	0.03	19,737.79
Total						**225,286.53**

As presented in Table 4, the Total Energy Embodied, summing all elements results of this model, was 2225,286.53 MJ, or 225.29 GJ. According Tavares (2006), some international researches presented values of building energy embodied around 4.0 and 4.5 GJ/m^2. However in a Brazilian scenery, considering that environmental analyses inputs are not properly detailed in construction sector, existing data shows numbers around 3.0 a 4.0 GJ/m^2. The residence model tested in this paper has 106 m^2, and so the final embodied energy value is 2.13 GJ/m^2. This can be considerate a reasonable result, once the level of detail is minimum because only seven elements composed the BIM model.

The proposed methodology generated results in non-editable tables, so using others software as a complement became necessary to process and compile data on a useful way. However, the primary advantage observed was the facility and processes simplification. When Shared Parameters are created, it is possible to use them in any project or model. The same thing occurs with Type Parameters, whose values will be automatically generate every time that these parameters are used again to specify a Family element, since it has been correctly saved. So if the method is applied many times by the professional who does project review or environmental and life cycle analyses, over time it will be created a complete and diverse element library with parameters previously defined. Then, once all data had been insert already, during antecedent projects, to apply a new assessment it would be necessary just to generate tables from new model. Except to transportations parameters, that changes in function of distances, type of vehicle and fuel.

Using BIM tools allows to rise projects performances, making it easy and reducing time of work. Therefore, it is relevant that these aspects be achieved by proposed methodology. Another significant characteristic observed during methodology processes is the facility in to modify project elements, shapes and anything else, without need to calculate or reinsertion data and numbers of elements changed. For example, if you change the room area by modifying wall position or its measures, so Revit will calculate new volumes automatically, and then the final results also will be updated at the same time. Conventional LCA process usually uses spreadsheets to calculate energy parameters from estimated volumes and materials quantitative, based on building areas, So in those cases, if changes are made on elements or areas, values alterations will be done manually at the spreadsheet, and all volumes would need to be recalculate, modifying again the materials quantitative to generate new results. It is an exhausting rework and also would have a risk to occurs several errors, because usually a lot of modifications are made in a project during deseing stage.

6. CONCLUSION

The proposal of testing a new methodology of a building Life Cycle Energy Assessment for pre-operation phase occurs from lack of simple tools and practices that help in selection of materials by designers in AEC industry. Results obtained in this paper are satisfactory once the proposed methodology is viable and accessible. The main differential characteristic of the method is the facility to calculate values of embodied energy, testing many different materials and several design layouts, without need a lot effort in data insertion, volumes and mass calculus or to estimate quantities.

Thus, it is possible to legitimize achievement for what BIM is aiming to: reducing efforts; rising projects its processes performance; and to accurate and organize information. There are still some little troubles and difficulties on new BIM tools, but it is in constantly technological evolution.

Finally, the proposed method in this paper contribute to impulse and to incentive environmental impacts analyses on construction industry, allowing it to be used in first design stage to appropriate material selection and improving sustainable choices. Building materials and processes decisions based on energy consumption should measure all impacts caused from all production cycle and resource transportations, connecting this with building energy performance and its further deconstruction and recycle. For that reason, this study also propose a link from BIM model and embodied energy analyses to a sequel on the LCA, involving building efficiency energy simulations and thermal and acoustic comfort conditions in operation phase at future researches.

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