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SOFTWARE APPLICATION FOR EMBODIED ENERGY BUILDING CALCULATION: A REVIEW

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ABSTRACT

Information technology applications used to facilitate work in the construction industry are growing. One of them is an application to calculate embodied energy. This calculation, especially on embodied energy material, is important in the building design phase because it can be used as the basis for various determinations of value of building energy and carbon emissions generated by buildings due to construction activities. By using the right tools in the embodied energy calculation, the building planner can determine the right embodied energy value, so that it can support building energy mitigation. This paper aims to explain the use of embodied energy building calculation software that have been developed to provide an overview and support research development of embodied energy building in Indonesia.

Keywords: Calculation; embodied; energy; review; software.

INTRODUCTION

The use of information technology for the construction industry is increasing especially in Indonesia. This information technology is used to facilitate construction work starting from building design, structural calculation, cost calculation, and so on. One that is starting to develop is the use of information technology in the form of applications to calculate and analyze the value of embodied energy building materials as the initial phase in a building life cycle. This life cycle is an essential phase to the built environment including pre-construction (covering the material extraction phase and manufacturing/production phase), construction, operation and maintenance, and demolition phase (Wahyuni et al., 2017). It has a phase frequently known as the phase of the cradle to grave. In every life cycle, buildings always consume energy. According to the United Nations Environment Program (2010) in Pratiwi (2020), the construction sector consumes 40% of the total energy in the world. In addition, according to Huang, et al. (2018), the construction sector in developing countries has the potential to cause approximately 60% of the total global CO_2 emissions (direct and indirect carbon emission intensity) in the atmosphere. This value is greater than the value of carbon emissions in developed countries. Energy consumption and CO_2 emissions resulting from the impact of construction activities will cause environmental damage in the future.

Building energy consumption is classified into two categories: operational energy and embodied energy (Dixit, 2012). The former becomes the most widely discussed in many literatures and research, while the latter is rarely discussed (Pratiwi, 2020). Embodied energy, according to Treloar (1998), is all energy that is inherent or consumed in all stages of activities to support a process of making an object or product. Embodied energy can be seen from two things: embodied energy contained in building materials and in the overall energy cycle of the building (Jurizat, 2020).

In addition, Dixit et al (2014) also described a model of energy contained in all phases of the building life cycle (Figure 2). Building embodied energy is not only in the material production phase, known as initial embodied energy, but also seen in the construction phase, building use phase, and building demolition phase. At the operational phase, the embodied energy is called repeated embodied energy that occurs due to building maintenance, especially in the replacement of new materials or during building renovations. If all phases of embodied energy are accumulated, the term Life Cycle Embodied Energy (LCEE) will appear. The calculation of embodied energy value is actually determined by the researcher who will assess the embodied energy depending on what phase will be limited. If the researcher wants to assess the overall LCEE, the phase taken is the Cradle to Grave phase. However, if the conducted phase is only up to the construction process, then the phase taken is the Cradle to Gate phase.

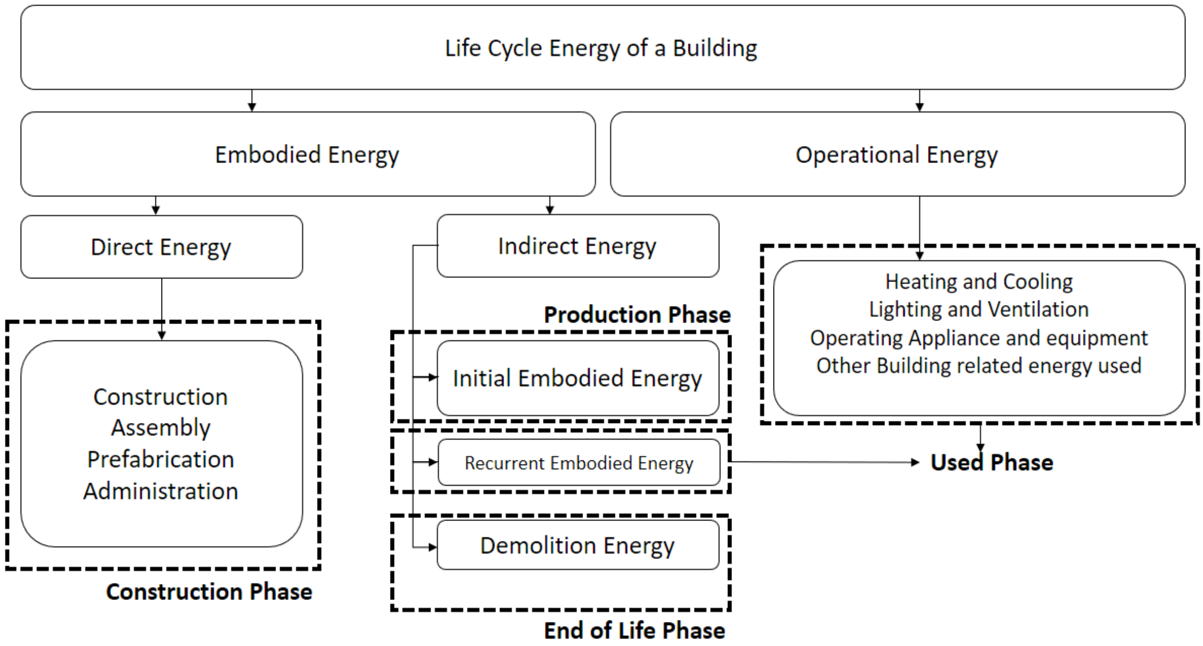


Fig. 1. Energy Model in Building Life Cycle (Dixit, 2014)

The analysis of embodied energy calculation is related to the analysis of carbon emissions because it uses the material volume variable as one of the calculation variables. The analysis of embodied energy and carbon emissions is closely related to the value of material quality (Zuraida, 2013). However, according to Zuraida (2013), the calculation of embodied energy and carbon emissions has differences in process and product aspects, and in the inventory of data sources. Embodied energy is calculated based on empirical data in the field and under the context of research site, while carbon emissions are calculated based on secondary data from the data results of collected by an authorized organization. However, both embodied energy and carbon emissions concern with fuel and cost as calculation parameters (Zuraida, 2013). Combining the analysis of embodied energy and carbon emissions in a Life Cycle Analysis or Life Cycle Assessment (LCA) study is able to fully explain the material quality in terms of products and processes so that it can provide an assessment of the environmental impacts that occur due to building construction activities. Therefore, this paper has the purpose to describe some types of software that has been developed to calculate or perform building embodied energy calculation and analysis.

Various environmental impacts caused by energy consumption, such as carbon (CO2) emissions, indirectly make embodied energy an issue to be considered by the world today, for example climate change (Jurizat, 2020). Embodied energy is also very important to reduce total energy consumption in a building (Dixit et al, 2014). By conducting embodied energy analysis, especially in the design phase, mitigation can be carried out to reduce embodied energy so that it can contribute to reducing environmental impacts.

The determination and calculation of embodied energy includes a standard widely known as the LCA referring to the standards of ISO 14040, 14044, and also International Energy Agency (IEA) in Annex 57 regarding Evaluation of Embodied Energy & CO2 Equivalent Emissions for Building Construction (Energy Building and Community Program, 2016). Guan et al. (2015) examined the implementation and demonstration of LCA analysis in the case of residential buildings. The research revealed that the building embodied energy has a varying value in portion of 10-30% of the total building energy. Meanwhile, the operational building energy value has a portion of 65% to 90% of the building energy consumption. Building demolition energy (end of life) usually has a value of less than 4%. Overall, the operational energy is indeed the biggest one of the entire life cycle, but what needs to be realized is that the embodied energy of material seems to appear suddenly even though the building has not been operated because the material formation also uses and requires energy. This is often overlooked by building construction stakeholders.

LCA is usually carried out at various stages. The first stage is to determine the objective and calculation method of the embodied energy. The second one is to conduct the inventory analysis by collecting input and output data and determining kind of emission model. The third is to conduct an impact assessment that will occur in the future by interpreting the results of data inventory to analyze the impact on the environmental issues. The last is to interpret the results that have been formulated to provide recommendations for environmental improvement of the issues raised. Figure 2 describes the LCA framework.

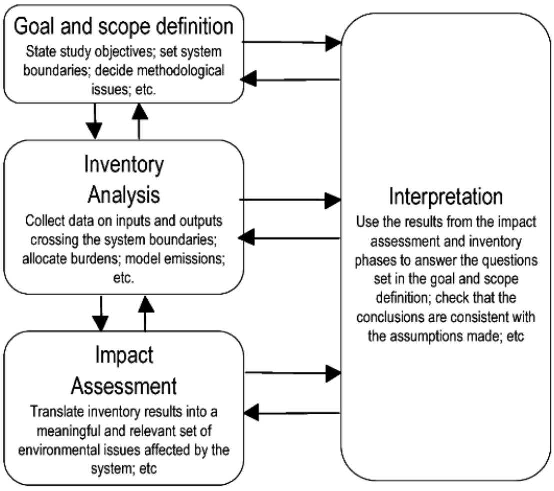


Fig. 2. LCA Framework
(Source: ttps://www.semanticscholar.org/paper/LIFE-CYCLE-ASSESSMENT-(LCA)-OF-DOMESTIC-VS.-Case-on-Mu%C3%B1oz-Hospido/64fb07dbb45136ee741e33ce8669a10be52c9734/figure/0)

The arisen question is about the critical and important phase of the embodied energy calculation indicating that the building being built has a significant impact on the environment. Newly built housing in Australia has an average embodied energy of around 1000 GJ. This value is equivalent to the operational energy value of the building for about 15 years (CSIRO in T. Ibn Mohammed, et al 2013). For a home that lasts 100 years, this is more than 10% of the energy used in life (Tucker and Ambrose, 1997). Wahyuni et al. (2017) also stated that the design phase is a critical phase in determining the value of building embodied energy, especially in determining the embodied energy material or initial embodied energy and contributing to LCA in the early stages of building cycle. The determination of embodied energy material calculation is by calculating the total energy used to mold the building materials starting from the material extraction process, material transportation, material manufacturing in the factory, maintenance process, material demolition, and material possible energy that can be reused or recycled. The overall energy accumulated in the entire process of the material life cycle is then called embodied energy building material as described in Figure 3 below:

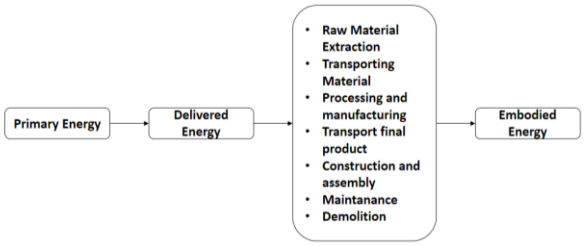


Fig. 3. The process of accumulating the embodied energy material value (Source: Haynes, 2013)

Figure 3 above formulates the amount of embodied energy material determined by several factors, namely:

- Energy of material extraction process
- Energy of transportation that transports semi-finished products
- Energy during material processing and manufacturing
- Transportation energy of final material products
- Material assembly energy
- Material treatment energy
- Material destruction energy

The basis for the used embodied energy calculation is usually a single material unit model that requires similarity in the calculation unit according to the Embodied Energy (EE) unit, namely MJ/Kg (Wahyuni, 2017). The single material unit is then converted by calculating Material Unit Analysis (MUA), which is derived from the unit price analysis commonly used in Indonesia to calculate the coefficient and volume of buildings. The entire volume of building materials will later become the basis for determining the results of the accumulated calculation of the overall EE value. In addition, the EE value is also influenced by the density of material and inventory EE coefficient. The EE coefficient calculation for this material refers to the carbon and energy inventory data (Graham et al, 2011 in Wahyuni, 2017). Calculation of EE value is obtained from the following calculation formula:

$$\text{EE (MJ)} = \text{Material Volume (m}^3\text{) x Material Unit Weight (Kg/m}^3\text{) x EE Coefficient. (MJ/Kg)}$$

METHODOLOGY

The research methodology of this paper consists of the following stages:

1. Reviewing systematic literature and collecting examples of using software for calculating embodied energy,
2. Grouping the results of software data collection descriptively to see the types of software frequently used in calculating embodied energy,
3. Describing the results of grouping the types of software descriptively to determine the type of data and analysis of the resulting embodied energy so that it can become a reference in calculating the appropriate embodied energy required by building planners, and
4. Compiling a description of prospects and constraints in developing software for calculating embodied energy so that it can be developed widely in Indonesia.

RESULTS AND DISCUSSIONS

Software that has been developed in calculating the building embodied energy

Technology that develops globally can be a significant cause in the development of construction industry. The embodied energy calculation has also followed the development of technology, which can be seen from the emergence of several software used to analyze the embodied energy of buildings. In addition to analyze the value of the building embodied energy, another function of the software development is to provide several alternatives materials that have low value in embodied energy and are still environmentally friendly. It can also present attractive data visualization for building planners to be presented to the clients or contractors.

The basic idea to develop software to calculate the embodied energy value is based on the calculating algorithm. The important and influential data in the embodied energy calculation is data on building materials related to the material density and energy coefficient, which is then inputted into computer programming so that users can easily calculate the value of the building embodied energy. These data refer to applicable standards, for example on material data containing in Inventory of Carbon and Energy (ICE) published by Bath University.

Three types of software have been developed, namely 1) using additional plugins in architectural design software; 2) using online web pages; and 3) developing personal computer (PC) or Android smartphones programs-based applications. Some of the software that has been developed to calculate or perform embodied energy analysis in buildings are described in table 1.

Each type of software developed for embodied energy calculation has uniqueness, such as method and user interface that are described in the following examples:

Table 1. Description of the types of software in the analysis of embodied energy calculations

No	Type of Software	Software Name	Type of analysis output
1	Additional plugins in architectural design software	Autodesk Revit with Material Takeoff and Plugin-BIM semantic (Primasetra, 2020; Dixit 2016; Schwartz, 2016; HBERT)	Numerical and graphics data of embodied energy and carbon emissions of all building material components
		Rhinoceros-Grasshopper combined with Autodesk Revit (Maassarani, 2017; Surendran 2015)	Numerical and graphics data of embodied energy and carbon emissions of all building material components
2	Online web page	Carbons hack design (https://www.carbonshack.com/embodied-energy/?zip_code=40512)	Overall embodied energy value of the material for each building component and the standard embodied energy value set by the respective regions (limited to the United States only)
		PDX (http://web.pdx.edu/~cgriffin/eecc/#home)	EE value in the building structure system
		B-Panel (http://www.b-panel.com/b-panel-embodied-energy-calculator/)	EE value in the architectural wall components
		Edge (http://app.edgebuildings.com/)	Water efficiency, energy, and materials value of a building design The embodied energy value described is the overall EE value of the material in units of MJ/m2.
3	Development of personal computer (PC) or Android smartphones programs-based applications	SimaPro	Numerical data and graphics data of embodied energy and carbon emissions of all building material components
		Android-based EE Calculator (Wahyuni dkk, 2017)	Embodied energy and carbon emissions calculation of all building material components and material substitution calculation for several alternative material uses (in the form of numerical data and graphics data)

1. Using additional plugins in architectural design software

Plugins are generally an additional tool or method available in the software, but some of which are manually installed to the software because the software has limitation to present the proper analysis for specific research purposes. One of the software discussed in the embodied energy calculation is Building Information Modeling (BIM)-based software using Autodesk Revit software. In BIM, embodied energy data processing can be done in two methods: 1) collaboration of BIM and statistical software such as Excel and 2) development of BIM plugin software by manipulating Application Programming Interface (API). The first process is called designer input, which is the material take-off method to create a schedule table for building components including unit weight of materials, the volume of components, and inputting EE coefficient data, for example Inventory o Carbon and Energy (ICE) (Inventory of Carbon and Energy, 2011) and weight data of whole material. These variables will be needed to analyze the embodied energy calculation for each building component.

Primasetra et al (2020) had tested the material take-off method for calculating the embodied energy, by conducting experiments on wall materials in the BIM model that has been made from previous research. Material take-off method can be created on the Schedule tab. Figure 4 below is an example of user interface of material take-off method using Autodesk Revit software to calculate the value of building embodied energy.

The results of table data analysis above can be extracted and converted into text data that can be processed by statistical software, such as Excel, to be accumulated and processed into graphics data to see the percentage value of material in a designed building as shown in figure 5.

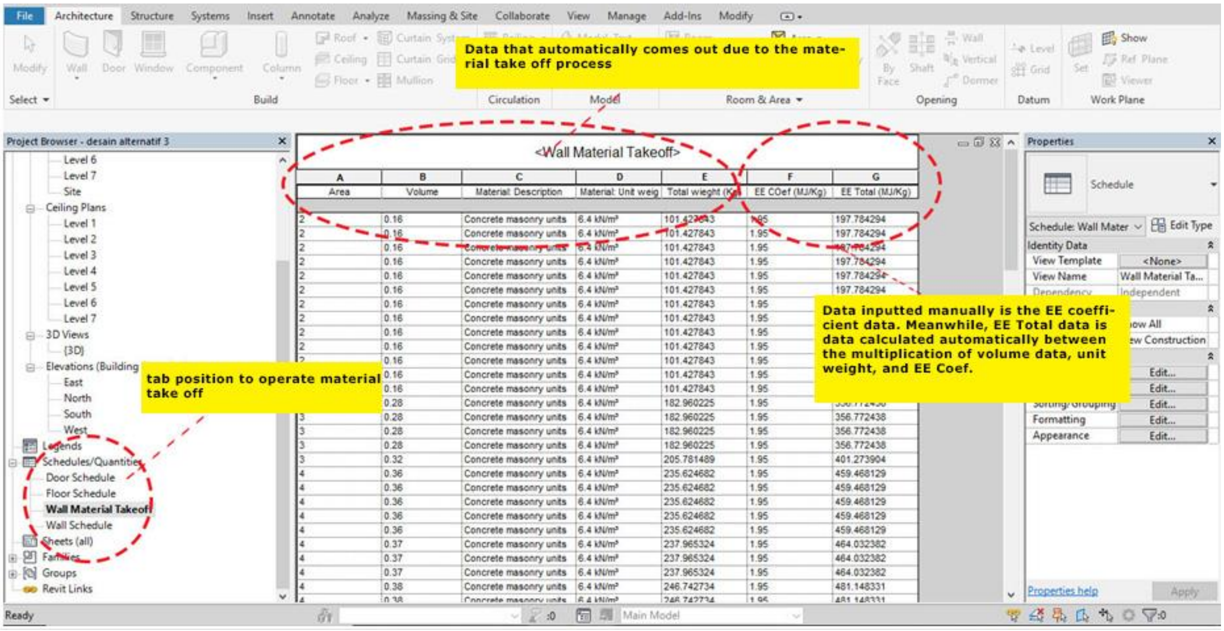


Fig. 4. Material take-off user interface to calculate embodied energy

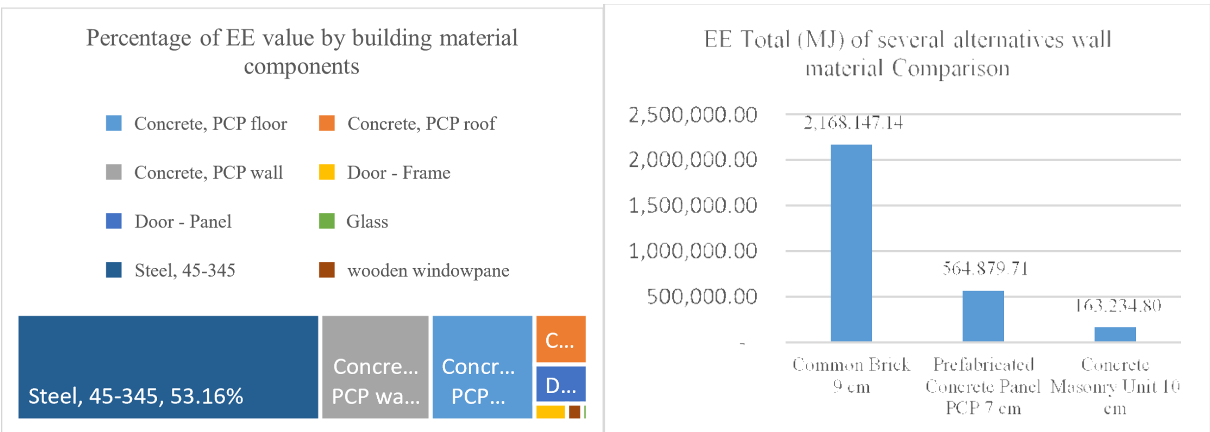


Fig. 5. (Left) Graphics data, distribution diagram of the percentage value of embodied energy of all building components. (Right) The distribution diagram of the comparison of the embodied energy value between several alternative wall materials (Source: Primasetra et al. 2020)

The process of embodied energy calculation using other plugins is to use semantic BIM. Schwartz, 2016 had specifically conducted research on BIM integration and LCA analysis using the semantic BIM method using the BIM programming language to then be derived into the BIM software plug-in system used. The main concept is to enter each parameter of material carbon emission into BIM programming language as input data, which can automatically calculate the value of carbon emissions.

The results of Schwartz's research (2016) were then developed into a BIM Software plugin product called HBERT with a company called Hawkins Brown. This product is an extension of BIM software, namely Autodesk Revit, making it easier to calculate carbon emissions in building materials because it is integrated with the BIM software. Figure 6 below presents the results of the data example of carbon emission analysis developed by HBERT:

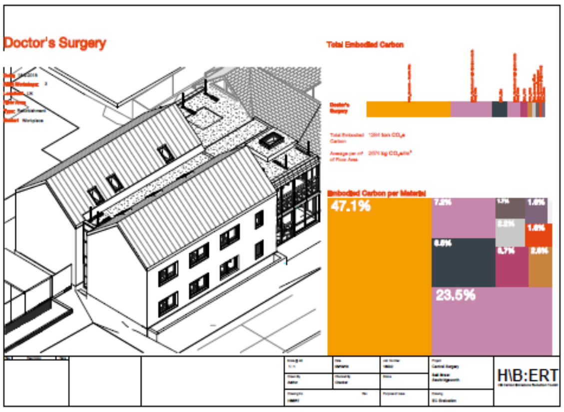


Fig. 6. Graphics data from the analysis of carbon emissions in building materials using BIM plugin (Source: HBERT, 2017).

2. Online web page

The other type of embodied energy calculation software is online web page. This type purposes an easy analysis process. Users or designers can easily access and input the building data to the website and get the result instantly. Its examples are Carbons Hacks Design, PDX, Edge, and B_Panel web pages. The used principle is in HTML programming where the data of building component material has been inputted into the web page, so that users can easily enter the parameters of the designed building components. After entering the appropriate parameters, the analysis results of the embodied energy value are automatically accumulated on the web page. Each applicator has a characteristic in the analysis of the value of embodied energy. Table 2 below explains the differences and characteristics of User Interface of each applicator.

3. Development of personal computer (PC) or Android programs-based applications

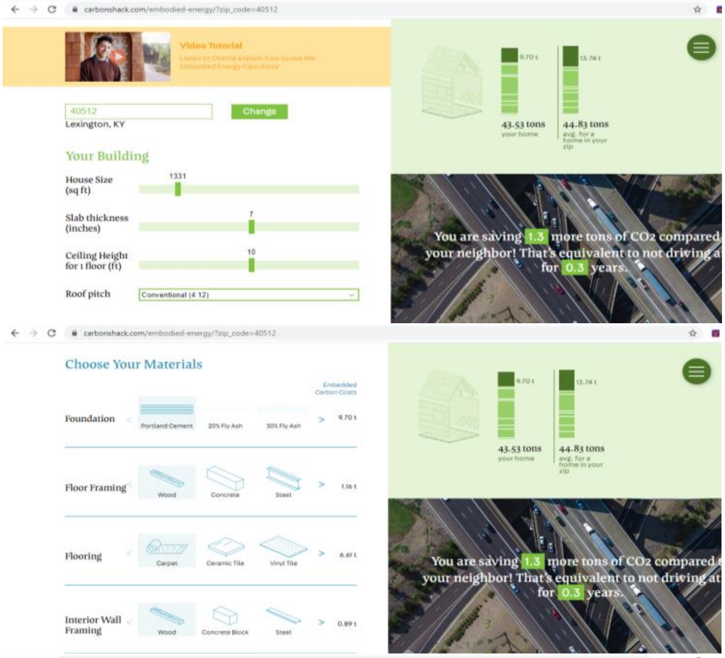
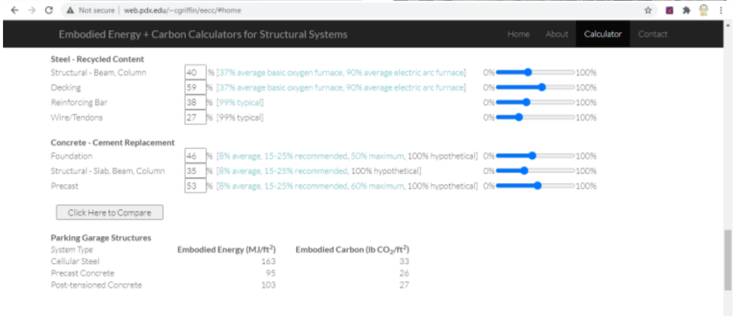
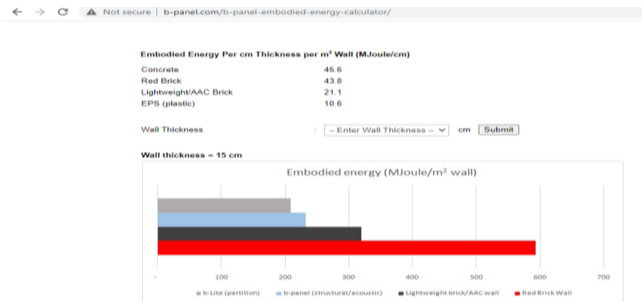
The third type of software is personal computer (PC) and Android programs-based software that are specifically developed to calculate embodied energy, for examples SimaPro and EE Calculator developed by Wahyuni et al. (2017).

SimaPro is one of the recommended software in ICE book to calculate embodied energy. SimaPro can analyze the entire LCA phase. The workflow of SimaPro refers to the LCA steps, namely determining objectives and scope, checking the inventory of database-based process, conducting analysis, and providing interpretations. SimaPro is not only limited to building LCA analysis for construction industry, but also performs analysis in other industrial fields that require an environmental impact analysis assessed from the carbon emissions released. The working method on SimaPro is quite easy. Users only need to determine and enter the raw material parameters, manufacturing process, forming process, and so on into the columns and tables that have been prepared. Inventory data on the value of material energy and the process of its formation having international standards are available in the software. The results are numerical and graphics data and a flow-chart for the life cycle of each process, so that each energy portion of each life cycle can be found.

The following is User Interface and analysis results using SimaPro software:

Fig. 7. User Interface and LCA analysis results using SimaPro (Source: Pre, 2016)

Table 2. Figure of differences and characteristics of User Interface of each applicator

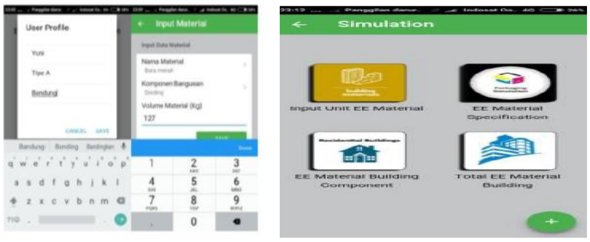
<table>
<tr><th>No</th><th>gure of web page user interface</th><th></th></tr>
<tr><td>1</td><td>
</td><td>Carbons Hacks Design
This method is by inputting the value of building area, floor thickness, and ceiling height. In addition, the materials per building component can also be selected. The standard value and material properties for embodied energy are limited for the area in the US. However, the total value of embodied energy can be analyzed and give information for the designer.</td></tr>
<tr><td>2</td><td>
</td><td>PDX
The framework of this EE calculator website is by inputting the percentage material building value designed by looking at the material standards listed in the columns available on the web page. Once inputted, the total value of embodied energy and embodied carbon will be accumulated automatically. However, this web page portal is only limited to structural elements of the building.</td></tr>
<tr><td>3</td><td>
</td><td>B_Panel
This software is owned by the wall material applicator.
Its method is by simply inputting the thickness of the wall. This software is only for calculating and comparing the value of embodied energy between each type of wall.</td></tr>
<tr><td>4</td><td>
</td><td>Edge
This software does not only calculate the energy embodied value, but also the overall energy efficiency value of water use and building operations.</td></tr>
</table>

Besides SimaPro, software that has been developed to calculate the embodied energy value is an Android-based EE calculator for smartphones developed by Wahyuni et al (2017). The development of this software has been adapted to the context of measurement in Indonesia and focuses on measuring the embodied energy value of simple residential buildings. The created algorithm framework is based on the calculation of unit price analysis of building materials determined by the working coefficient, material units, and material volume factors. After that, the coefficient data of material EE value is inputted. The results of the embodied energy calculation analysis using the Android-based EE calculator are divided into three types, namely the EE value based on material specifications, based on building components, and of all building components. Using an Android-based application to calculate the embodied energy value of building materials is easy because it is operated using a smartphone. Users must enter the type of material for each component consisting of wall, foundation, roof, and ceiling components. This software application also makes it easy for users to enter inventory data for the EE coefficient values from their own measurements, so that the finalresults of the embodied energy calculation analysis are in accordance with the Indonesian context. The following is an example of user interface and the results of the embodied energy assessment of a residential building.

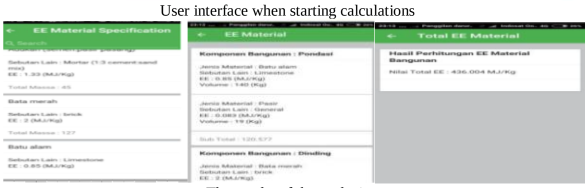
The discussion above describes the aspects that can be assessed from each of the developed software. The following is the result of the description (Table 4).

The table presents various results due to the advantages and uniqueness of each type of software. The software that can most assess the embodied energy aspect is Edge and integrated BIM, both material-takeoff and semantic BIM. Edge is software that has been recognized by green building assessment institutions in Indonesia, as well as in Asia, America, and Europe. The calculation of the EE value using Edge can be adjusted to the region where the project will be built and adjusted to the building typology starting from residential, office, or other commercial buildings. Green Building Council Indonesia (GBCI) institutions also provide certified Edge training, so that architects can perform and have the credibility to assess their design buildings legally. Using Edge online is easy to implement and free of charge, so that all people can access it. It is expected to save time and provide validity for architects in determining the energy value of the designed building.

Table 4. User interface images and analysis results of Android-based EE Calculator



User interface when starting calculations



The results of the analysis

(Source: Wahyuni et al, 2017)

SimaPro is another software that has become a standard and reference in calculating EE values recommended by Bath University in the book of

Table 3. Assessment aspect of each software

No	Software	Assessment aspects						
		Data Result	EE Value of Building Structural Components	EE Value of Building Architectural Components	Carbon Emission Value	Standard Value per Region	Whole Energy Efficiency Value	Provide an Alternative to Use Material with Low EE
1	Integrated BIM Material Take-off (Autodesk Revit)	Numeric and graphic	Yes	Yes	Yes	No	No	Yes
2	HBERT (Semantic BIM Autodesk Revit)	Numeric and graphic	Yes	Yes	Yes	No	No	Yes
3	Carbons Hacks Design	Numeric and graphic	Yes	Yes	No	Yes	No	No
4	PDX	Numeric	Yes	No	No	No	No	No
5	B_Panel	Numeric and graphic	No	Yes	No	No	No	Yes
6	Edge	Numeric and graphic	Yes	Yes	No	Yes	Yes	Yes
7	SimaPro	Numeric and graphic	Yes	Yes	Yes	No	No	Yes
8	Android-based EE Calculator	Numeric and graphic	Yes	Yes	No	No	No	Yes

Inventory of Carbon and Energy (ICE). SimaPro is not a specific software to calculate the EE value, but can calculate the energy value in the LCA as a whole. In addition, SimaPro is not only a specific software used for building construction, but also for calculating the overall energy value of a process involving energy, for example in manufacture industry.

The embodied energy calculation integrated with BIM has an advantage in the aspect of determining various alternative types of embodied energy material calculations that can be done in real-time because the architectural model can be directly calculated with plugins contained in BIM software such as Autodesk Revit. The advantage of using this BIM is that the data used is the type changes of building material using the existing BIM data or the BIM material data inputted by architect. These changes and inputs result in the embodied energy value calculation that will change quickly and automatically. Another advantage is that plugins using semantic BIM can be developed independently using the help of programming language development software, such as those done by Schwartz and HBERT (2016).

Another promising software to develop is an Android-based application, one of which was developed by Wahyuni et al (2017). It can make the process of embodied energy calculation easily since it is connected to a smartphone as the lifestyle of today's society. In addition, the use of Android applications in calculating EE value will be one of the solutions to the weaknesses of EE calculations, which is the difference in the standard values of each country (Dixit et al, 2014). This condition occurs because of the differences in the parameters of each country due to different data quality (it has something to do with the geographic and data collection technology of each country), calculating embodied energy method, system boundaries, and primary or secondary energy, which is inputted or not to the embodied energy calculation. The Android-based applications allow software developers to enter local material data, so that the calculation results of the EE value will be contextual to the location where the project is built. Android-based software development is also easy to access and has been done by many people. However, this Android-based software application has limitations, namely no longer available on the platform of Android software service provider and still limited to calculating the EE value for simple residences. In addition, Android-based applications do not directly integrate with the architectural design model, thus requiring additional manual ways to enter building design data. However, this software can be an example that can be developed in the future in calculating the building embodied energy value because of its easy use and affordability to many people.

The development of the application for embodied energy calculation has raised awareness to care about the environmental impacts of construction activities. In addition, embodied energy calculation software has been developed so that researchers or building designers are able to assess embodied energy at any phase in the building's life cycle, from the Cradle to the Gate phase to the Cradle to the Grave phase. The weakness of calculating the embodied energy regarding the standard material data of each different country can also be solved by developing an embodied energy calculation software. This software has also the flexibility to enter local data so that the final result of calculating the value of the embodied energy will be valid according to the context of the location.

Prospects and constraints of software development for embodied energy materials in Indonesia

The prospect of software development for calculating the value of embodied energy building materials in Indonesia has been good for research purposes and construction industry practices. The analysis and calculation of embodied energy and carbon emissions will be easy to project so that designers can get building designs that have low energy values. This is a measurement of building energy mitigation in the design phase. The embodied energy value also determines the carbon emission value, which is considered to be one of the causes of worsening global warming. Therefore, with attention to the embodied energy of building materials, building energy mitigation can also be achieved to reduce carbon emissions. This is in line with Indonesia's commitment to reduce carbon emissions by 29% by 2030 (mediaindonesia.com article dated 27 November 2019). The government has also enacted Law Number 17 of 2017 concerning the 2005-2025 Long-Term Development Plan having a vision of realizing “Eco-friendly and Sustainable Indonesia” (Murniningtyas, 2012). The use of software for calculating the embodied energy value using BIM software-based plugin supports the implementation of BIM-based construction activities because the use of BIM itself has been supported by Regulation of the Minister of PUPR Number 22 of 2018. In addition, the regulations for building establishment, especially multi-stories buildings, have also referred to the green building standards issued by GBCI. One of the standards is to use low carbon and green-certified materials. The use of Edge software has become a standard recognized by GBCI. In addition, GBCI also conducts training to use the Edge application. The more building designers are concerned with the embodied energy of building materials, the less they can have environmental impacts and the more reduce carbon emissions due to construction activities.

Apart from the Edge software, some of the software that has been discussed previously also accommodates researchers or building designers to input the local material data values, such as BIM integrated with the analysis of embodied energy calculations using Autodesk Revit software. Here, a BIM software is frequently used and leading the BIM software market as much as 49% (NBL, 2013). The use of BIM integrated with embodied energy analysis is able to provide the advantage of being able to assess the building embodied energy and quickly iterating alternative designs. In addition, it also serves to minimize manual data input errors because the EE value data has been documented directly into the BIM of component material data. Besides that, it also supports the implementation of BIM-based construction activities in Indonesia, which have been supported by the government in the Minister of Public Works and Housing Regulation Number 22 of 2018.

Another promising software in Indonesia is software similar to the online-based Carbons Hacks Design (Figure 8) from the United States. This Carbons Hacks Design has the advantage of containing local embodied energy material data, which can be directly accumulated with designs by planners and contains embodied energy material standards recommended in the region of the country. If the results of the embodied energy analysis appearing from the design results have a higher value than the standard value, the notification and recommendation will state that the design is not in accordance with the standards recommended by the region in the country. In addition, the software is free to access. This would be promising if this method can be adopted by Indonesia.

The following points are the constraints in software development for building embodied energy calculation in Indonesia:

- The used material data is international standard-based material inventory data, so that further research is needed on local material inventory data made in Indonesia to make the calculation of embodied energy value is precisely targeted in accordance with the Indonesian local context.
- The existing software is not used by Indonesian construction industry players, so that there needs to be a lot of socialization in its application. This can be developed by collaboration of all stakeholders (academics, practitioners, and government).
- Software development for calculating embodied energy in Indonesia requires cross-sector cooperation including architecture, materials engineering, and informatics engineering. The development of cross-sector research in Indonesia is still difficult to be achieved. However, this is also a good prospect for developing a wider perspective and science in Indonesia.

CONCLUSION

Various types of platforms exist for calculating the building embodied energy. Each type has its own characteristics and purposes. Software development for embodied energy studies in Indonesia has been carried out such as Android-based application on smartphones aiming to make the process easily and predict the value of building embodied energy, so that the architect can be aware about the environmental impact and reduce carbon emissions due to construction activities. Besides that, a software application that has been recognized by Green Building Council Indonesia standards is Edge software, which has also been recognized in various countries as Green Building software standard. The software development for calculating and analyzing the embodied energy building materials in Indonesia has a promising prospect because it supports the government's vision of environmental conservation as regulated in law. Some of the obstacles faced are the lack of local material data inventory so that additional research is needed to collect local material inventory data, limited access of software by architects, and the need for cross-sector research collaboration, so that the embodied energy software can be maximally refined. The implications of this research can later become the basis for researchers and architects who will conduct an analysis of building embodied energy to have a view on building designs that are low in embodied energy, so that they can reduce the environmental impact of construction. Thus, it is hoped that further research will be carried out related to software development for embodied energy studies so that it can be widely used by stakeholders in the construction industry in Indonesia.

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