ENVIRONMENTAL IMPACT EVALUATION ON CONSTRUCTION MATERIALS WITH THE INTEGRATION OF BUILDING INFORMATION MODELING (BIM) AND LIFE CYCLE ASSESSMENT (LCA)

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ABSTRACT

Technological developments, especially in the construction sector, have developed rapidly. The construction industry is one of the activities that consume energy, resources, and affects the environment. Therefore it is important to increase innovation and solutions to achieve sustainability standards. Several efforts were made to maintain environmental sustainability against global problems, namely the selection of building materials through an analysis of the impact of building materials on the environment called a Life Cycle Assessment (LCA). In this study, two types of curtain wall system materials, type (A), reinforced concrete, final coating, and type (B) brick, reinforced concrete, ceramic, and mortar will be compared. The method used in the completion of this research is a full building supply system in one way, namely the collaboration between Autodesk Revit and Tally which will then be analyzed again. The first step is to determine the type of material by calculating the total material requirements to be used or by modeling the building using Autodesk Revit. From the total volume of material that will be analyzed the impact of the building life cycle based on ISO 14040. The final objective of this research is to get the best alternative from the second material above. The results of the analysis supported the type (B) material which has a smaller effect than the type (A) material on the main environment that regulates global.

Keyword: *Autodesk Revit, Global Warming, Life Cycle Assessment, Tally*

1. INTRODUCTION

The development of technology in the industry, especially in the construction sector, has grown rapidly. The United States Energy Information Agency (US) predicts that by 2025, the level of global energy consumption will increase by 33% in developed countries and 91% in developing countries [1]. The construction industry is one of the activities that consume energy, resources, and will affect the environment. Therefore it is important to increase innovation and solutions to achieve sustainability standards. Some efforts were made to maintain environmental sustainability against the issue of global warming, namely by selecting building materials through an analysis of the impact of building materials on the environment called a Life Cycle Assessment (LCA).

The factors that influence the basic role of the environment and energy consumption during the Life Cycle Assessment (LCA) of building materials are raw material extraction, manufacturing, packaging, and transportation to the site, construction and installation, operation, demolition, and recycling. New strategies such as a green building approach, adoption of sustainable materials, and renewable energy systems are widely needed to reduce energy consumption, the greenhouse effect, and the environmental impact of building materials in the construction sector. In recent years the relationship between building materials and energy has increased. Therefore modern technology is needed to explore the various properties and capabilities of these materials. In addition, the type of building, climate, and level of economic development are important factors that play a role in determining energy consumption patterns in the construction sector [3].

2. LITERATURE REVIEW

Global warming or called global warming in English is the process of increasing the earth's temperature due to emissions of greenhouse gases and fossil fuels, methane gas, carbon dioxide. According to the Nature Resources Defense Council, global warming is a condition of increasing the average temperature of the earth's surface due to excessive concentrations of greenhouse gases. The impact of global warming is believed to reduce the quality of human life. Global warming is often associated with air pollution due to an increase in carbon dioxide (CO2) and greenhouse gas effects due to burning fossil fuels, land clearing, and other human activities [4].

Life Cycle Assessment is a technique used to assess the environmental impact associated with a product with the LCA stage, namely by compiling and taking inventory of inputs and outputs related to the product to be produced. Then evaluate the potential environmental impacts associated with the input and output of products, and interpret the results of the inventory analysis and impact assessment phase in relation to research objectives [2]. LCA studies environmental aspects and potential impacts throughout the product life cycle (cradle to grave) from raw material extraction through production, use, and disposal [2].

According to ISO 14040, LCA can help in several aspects including:

1. Identify opportunities to improve the environmental aspects of the product at various points in the life cycle.
2. Decision making in industry, governmental or non-governmental organizations (eg strategic planning, priority setting, product or process design or redesign).
3. Selection of relevant environmental performance indicators, including measurement techniques, and
4. Marketing (eg environmental claims, eco-labeling schemes, or environmental product declarations).

The scope of the LCA can be divided into four types of scope, namely:

1. Cradle to grave
   The scope of this section starts from raw materials to product operations.
2. Cradle to gate
   The scope of the life cycle analysis starts from raw material to the gate before the operation process.
3. Gate to gate
   The scope of the shortest life cycle analysis because it only looks at the closest activities.
4. Cradle to Cradle
   Is part of a life cycle analysis that shows the scope of raw material to material recycling [3].

2.1 Life Cycle Assessment (LCA) Phase

According to ISO 14040, the LCA phase includes the following things can be seen in **Figure 1.**

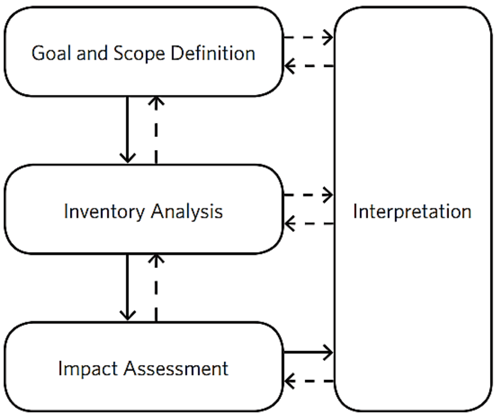


Figure 1. LCA Phase

2.1.1 Purpose, scope and definition of Life Cycle Assessment (LCA)

This first step will determine the purpose for which the LCA was created and describe the intended use of the LCA results. In this step, the scope and boundaries will be determined which define what processes are studied and the scope of the analysis. Before conducting an LCA, determining the objectives, scope, and definition is needed to consider the function and performance of a product to be studied. If the research is carried out as a whole building, it will determine the building system and life cycle stages that will be included or excluded from the assessment and the data sources that will be used. If the assessment aims to compare a product then the functional unit will show the areas and performance criteria.

2.1.2 Life Cycle Inventory (LCI) Analysis

The second step is inventory analysis, which is included in this stage which includes data collection and calculations to qualify the input and output of a product system (a complete phase from production, use, to disposal) along with the processes and emissions needed to carry out the LCA phase. which have been specified. This inventory is collected for material data settings that can be used in analysis ranging from material selection, material volume calculation, and other data collection which must be accurate because it affects the results to be obtained from the LCA output.

In addition to assessing the overall impact of the building, this study will examine two types of wall materials that will be used as a comparison for the purpose of making decisions regarding more sustainable materials. There are two types of materials used, namely:

- Type (A) includes modern building materials such as curtain wall systems, reinforced concrete, and finishes.
- Type (B) includes building materials such as reinforced concrete, bricks, ceramics and mortar, metal.

2.1.3 Impact Assessment

This phase aims to evaluate the significance of potential environmental impacts using the results of life cycle inventory analysis. This assessment can include an iterative process to review whether or not the objectives and scope of the LCA are met or not. The results of the analysis of the output to be issued for life cycle impact assessment are primary energy demand and five environmental impact indicators. Included in primary energy demand is total demand, non-renewable, renewable. Meanwhile, what is meant by five indicators of environmental impact are the potential for acidification, the potential for eutrophication, the potential for global warming, the potential for ozone depletion, and the potential for smoke haze formation. As shown in **Figure 2.**

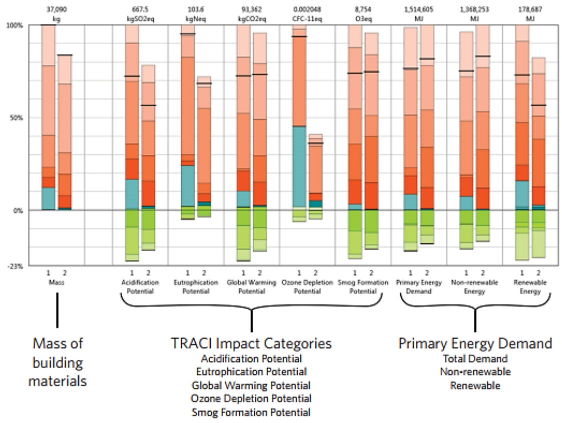


Figure 2. Impact Assessment Graph

2.1.4 Interpretation

Interpretation is the LCA phase where the findings from the inventory analysis and impact assessments are combined together according to purpose and scope. The findings from this interpretation obtained results in the form of conclusions and recommendations, decision making, consistent with the objectives and scope of the study.

The LCA interpretation phase involves validating a case study and analyzing the results of the case study. Because the Life Cycle Inventory (LCI) data is analyzed using the Tally database, the validation results will be displayed in the form of a report attachment containing a list of items for each material used according to the material that has been selected. The LCA results that have been analyzed should be examined carefully during this phase to understand the relationship between building materials and environmental impacts.

2.2 Standards & Parameters of Life Cycle Assessment (LCA)

The standard that becomes the reference for Life Cycle Assessment (LCA) is ISO 14040 Life Cycle Assessment, which discusses quantitative assessment methods for life cycle impact assessment and life cycle interpretation. ISO 14040 is a comprehensive standard covering all four phases of the LCA. There are three additional standards that complement ISO 14040, namely:

- ISO 14041 addresses the definition of objectives and the scope and methods of life cycle inventory.
- ISO 14042 is concerned with life cycle impact assessment methods and life cycle impact assessment methods and methods of interpretation of ISO 14043.

LCA standards refer to ISO 14040 - 14044, ISO 21930: 2017, ISO 21931: 2010, EN 15804: 2012, and EN 15978: 2011.

3. RESEARCH METHODOLOGY

3.1 Preliminary Studies

The preliminary study aims to observe the scope of discussion that will be used in research such as looking at global issues and problems that exist in the world of construction today and from previous research. A survey of the project that will serve as a case study, as well as examining difficulties that arise during the research and alternative solutions.

3.2 Early Identifcation

The initial identification stage is the stage to identify existing problems. Initial identification is done by looking at issues that are currently developing in the world of construction, especially in Indonesia. Included in the initial identification stage are:

- **Observation Stage**

  Observations were made with the aim of looking at problems that exist in the world of construction today and issues that are currently developing. From the initial identification, several things were obtained which later became the background for the research, namely the occurrence of the industrial revolution 4.0, Global Warming which we can currently feel, and from several previous studies from environmental-related survey institutions which stated that the level of world energy consumption continues to increase from year to year and actions that produce gas emissions that affect the survival of the next generation.

- **The Problem Formulation Stage**

  This stage is formulated based on the background that has occurred and has been explained in initial observations to answer the challenges of the times regarding industrial collaboration so that it can survive and continue to move amid the increasingly sophisticated revolution, namely the industrial revolution 4.0, and fulfill several government policies regarding the use of BIM and material development. The construction is considered more sustainable to minimize the impact of global warming that occurs.

- **Reaearch Purposes**

  This study aims to analyze the impact of using facade materials in construction buildings on the environment. By formulating the research objectives, two alternative materials will appear that will be used in this study, namely type (A) and type (B). Type (A) includes modern building materials such as curtain wall systems, reinforced concrete, and finishes. Type (B) includes building materials such as reinforced concrete, bricks, ceramics and mortar, metal.

- **Literature Review**

  The literature study carried out is sourced from research journals related to BIM and LCA, books, ISO standards, and BIM workshops in the 10 & 11 Engineering Forum by the WIKA BIM Team.

3.3 The Data Collection Stage

The data collection stage was carried out in the project which was used as a case study in this research. The data collection methods are as follows:

- Data obtained from field observations, namely shop drawings which will be used as primary data for this study and for the simulation process, analysis of the role of BIM and LCA integration. In relation to the Life Cycle Assessment, data collection is a phase where each product component is defined. Every input and output in a product system is interpreted into environmental indicators and this phase is called the Life Cycle Inventory (LCI). Data collection is carried out for each process in the material life cycle, namely the production process. In general, which is LCI data, namely product specification data (material type, the total volume of material), Life

Cycle Inventory (LCI) material production process type (A) and type (B).

3.4 Data Processing Stage

Data processing is carried out using Autodesk Revit software and Plug-in Tally because based on previous research, Tally is a powerful solver engine that adopts the GaBI database in LCA analysis. The following are the data processing steps as follows:

a. Planning a method of doing work
b. Determine the type of material used
c. Calculating the volume of the total material used or can be done by making modeling in Autodesk Revit
d. Functional unit and reference unit

3.5 Analysis and Evaluation Stage

The analysis and evaluation stage is carried out after the results of the data collection and processing that have been carried out on the project are used as case studies are obtained. From these results, several things were analyzed, including:

3.5.1 Determination of The Objectives, Scope, Definition of The LCA

The determination of the objectives and scope of the LCA is carried out with the aim of focusing research on what is being researched and not extending to things that are not the core of the discussion. It has been explained that the purpose of this LCA is to evaluate the building life cycle assessment of wall materials and the final result is a decision-making system for the materials to be used. The type of wall material used in this study is divided into two types, namely as follows:

- Type (A) includes modern building materials such as curtain wall systems, reinforced concrete and finishes.
- Type (B) includes building materials such as reinforced concrete, bricks, ceramics and mortar, metal.

3.5.2 Life Cycle Inventory (LCI) Analysis

According to ISO 14040, the Life Cycle Inventory (LCI) stage is a stage that involves data collection and data computation to measure the input and output of materials and energy associated with the product system under study. These inputs and outputs can cover the use of resources and what is released into the air, water, land associated with the system.

3.5.3 Life Cycle Impact Assessment (LCIA)

The LCA impact assessment phase aims to evaluate the significance of potential environmental impacts using the results of a life cycle inventory analysis. In general, this process involves linking inventory data to specific environmental impacts and trying to understand those impacts. The details of the impacts evaluated and the methods used depend on the objectives and scope of the study. This assessment may include an iterative process to review the objectives and scope of the LCA study and determine which research objectives have been met or to modify the objectives and scope of the assessment indicates that the objectives cannot be achieved. The impact assessment phase can include elements such as, among others:

- Classification (assigning inventory data to impact categories)
- Characterization (modeling of inventory data in impact categories)
- Weighting (collect specific results)

3.5.4 Interpretation

Interpretation is the LCA phase in which the findings from the inventory analysis and impact assessment are combined, or life cycle inventory, inventory analysis findings only, consistent with the objectives and scope defined in order to reach conclusions and recommendations. The results of the interpretation are the conclusions and recommendations for the decision-maker, consistent with the objectives and scope of the study. The interpretation phase can involve the iterative process of reviewing and revising the scope of the LCA, and the nature and quality of the data collected are consistent with the objectives set. The findings of the interpretation phase should reflect the results of the sensitivity analysis carried out.

4. RESULT AND DISCUSSION

To support this research, an object is used, namely a case study project. This research case study is a hotel building with 10 floors and a one-floor semi-basement. Based on the research objectives and data, the scope taken is the building structure, building facades (curtain wall and brick), and Life Cycle Assessment (full building assessment). LCA analysis uses a full building appraisal system with reference to the LCA ISO 14044 standard and in accordance with the GaBi database which has been used as a worldwide LCA analysis and will then be re-analyzed.

4.1 Life Cycle Assessement (LCA)

LCA is a methodology that aims to measure the environmental impact of a product or material, taking into account the entire life cycle from raw material extraction, manufacture, and transportation to site, construction, operation, and maintenance, to the end of its useful life and recycling or demolition. This integration is expected to help develop and expand frameworks, impact assessments, and data quality. LCA has been widely applied in the construction sector since 1990 as an important tool for evaluating the environmental impact of building materials during different life cycle phases of a construction project. This study applies the LCA methodology based on the ISO 14040 and ISO 14044 guidelines in the available database to achieve the objectives of this study.

4.1.1 Goal & Scope

At this level, the information will be selected in detail: system boundaries, variants and data sets, functional units, types and impacts of analysis, assumptions, and research limitations. The system limit refers to the LCA. In this research, the system boundary focuses on several phases during the life cycle in Cradle to Grave, including raw material extraction, manufacturing, operation, and end of life. The system boundary is not included in the construction phase as shown in **Figure 3**. The final phase of the building cycle or End of Life is divided into two, namely disposal and recycling.

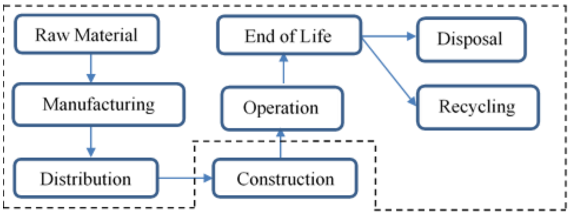


Figure 3. System Boundary Layout

Of particular concern is the list of impact categories to evaluate the actual impact of building materials on the environment. The functional unit, which describes the product or system being evaluated considers the entire building as one unit. According to technical standards, the average lifespan of buildings in this work is in the range of 50 years. However, the scope of this work is to consider the initial design stage of building a multi-story building. It aims to evaluate the environmental impact of building materials. To measure each category based on selected system boundaries and functional units such as the potential for acidification, the potential for eutrophication, the potential for global warming, the potential for ozone depletion, the potential for smoke generation, demand for primary energy, non-renewable energy, and renewable energy.

4.1.2 Life Cycle Inventory (LCI)

This phase includes details of environmental inputs from materials or materials. LCI is a group of elementary flows including all emissions released to and from the environment during the life cycle of a product or material. In other words, this phase considers all the inputs and outputs of the production system during the life cycle. So it can be said that this phase is very important to collect the correct data because it will affect the final LCA results. The distance to transport construction materials to the project site is assumed to be 8 km.

4.1.3 Life Cycle Impact Assessment (LCIA)

In this phase, the results obtained from the LCI data input that has the influence of the impact assessment method are translated into impact categories to make it easier to see the results that have been obtained. Environmental involvement such as raw material extraction, emissions, is translated into environmental impacts using impact assessment methods. The results presented in this study are based on an analysis of the building materials used in the work functional unit which considers the entire building as one unit. The following are the results of the full building life cycle stage of type (A) and type (B) materials in **Figure 4** and **Figure 5.**

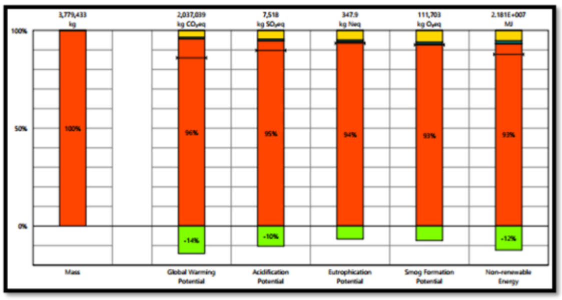


Figure 4. Type (A) material Life Cycle Stage

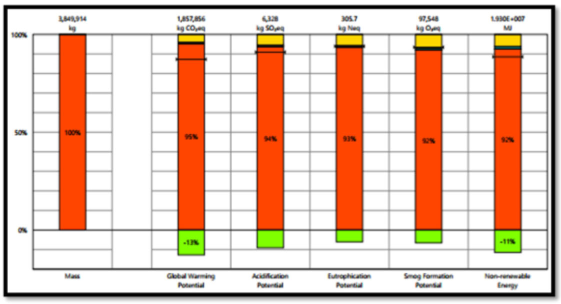
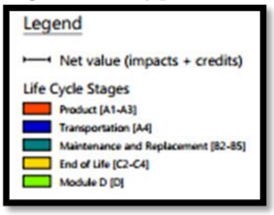


Figure 5. Type (A) material Life Cycle Stage



From the results of the life cycle analysis, the results are shown in **Figure 4** and **Figure 5** that the product has the largest percentage compared to other life cycle stages (marked in orange) of emissions released to the environment. And the biggest impact caused by the product is Global Warming with 96% of each type (A) and 95% of type (B).

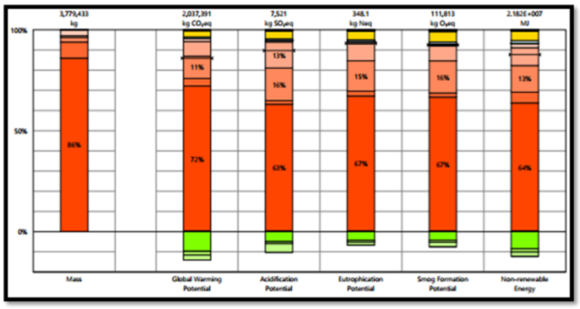


Figure 6. Results Per Stage by The Division of Materials Life Cycle Type (A)

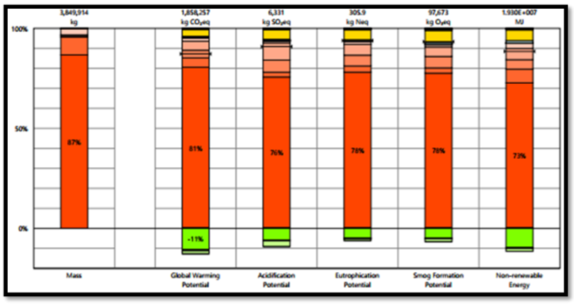
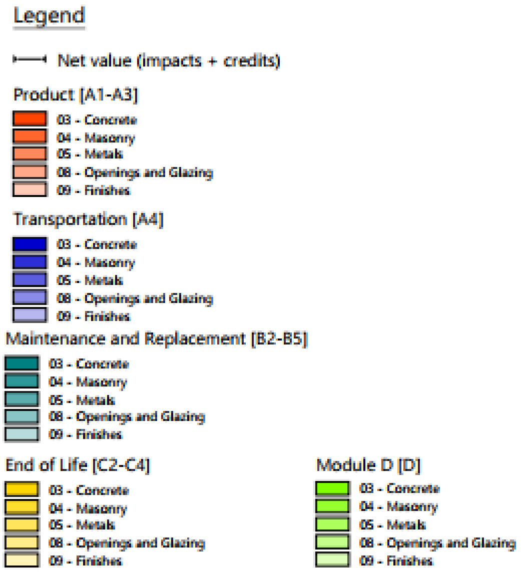


Figure 7. Results Per Stage by The Division of Materials Life Cycle Type (B)



From the results of the analysis per life cycle stage according to the material division grouping, the results are shown in **Figure 6** and **Figure 7** that Concrete has the largest percentage compared to the results of the analysis per other life cycle stage (marked in orange) on emissions released to the environment. And the biggest impact caused by the product is Global Warming with 72% for type (A) and 81% for type (B).

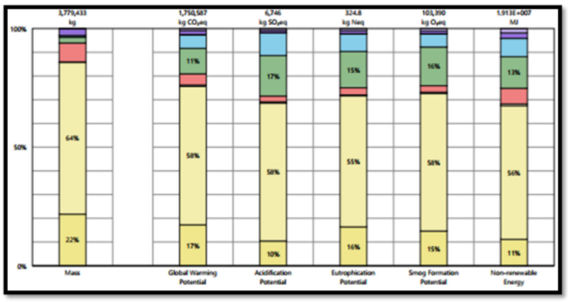


Figure 8. Results Per Division Broken Down According to Tally Input on Material Type (A)

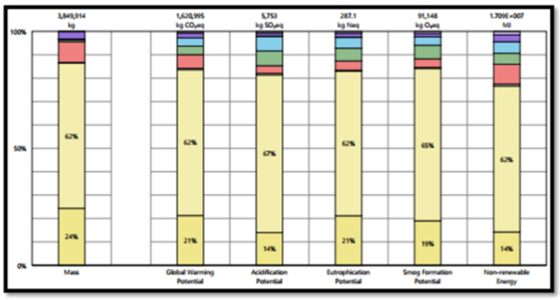
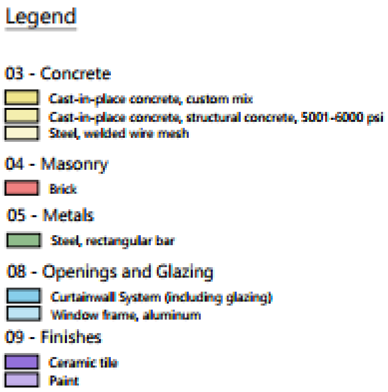


Figure 9. Results Per Division Broken Down According to Tally Input on Material Type (B)



From the results of the analysis per division that is detailed according to the input using the Tally Autodesk Revit plug-in tool showing the type (A) and type (B) materials in **Figure 8** and **Figure 9**, it is found that Cast-in-place Concrete, Structural Concrete, 5001-6001 psi has the largest percentage compared to the results of the analysis per other division (marked in yellow) on emissions released to the environment by 58% in type (A) material and 62% in type (B) material to Global Warming/Global Warming. The biggest impact caused by the product is Global Warming, Acidification Potential of 58% and 58% respectively for type (A) material and 62% and 67% for type (B) material.

4.1.4 Interpretation

Based on the evaluation carried out from the results of the analysis at the LCI and LCIA stages, it was found that the type (A) Curtain Wall System material had a lower environmental impact than the brick type (B) material. However, when compared to other constituent materials, the material group in type (A) has a lower environmental impact when compared to materials in concrete work such as floors. According to the analysis from the author, this is due to the volume of concrete material which is more dominant in this project work. And the greatest analysis result of this LCA process occurs at the time of production.

5. CONCLUSION

From the results of the full life cycle analysis of buildings, it is obtained the identification results according to the purpose that Production has the largest percentage of two compared to other life cycle stages of emissions released to the environment. Then the biggest impact caused by the product is global warming by 96% in type (A) materials and 95% in type (B) materials. Then from the results of the analysis of the material group used, it is found that the work that produces the greatest emissions to the environment is high quality concrete work.

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