Sustainable Civil Building Management and Engineering Journal Vol: 1, No 4, 2024, Page: 1-14

Greenhouse Gas Emissions Analysis

(Case Study: Construction of a Satpol PP Building)

Khalijah Herma Wytti*, Fajar Sri Handayani, Setiono

Civil Engineering Study Program, Faculty of Engineering, Sebelas Maret University

DOI:
https://doi.org/10.47134/scbmej.v1i4.2699
*Correspondence: Khalijah Herma Wytti
Email:
khalijahermawytti@student.uns.ac.id

Received: 01-08-2024
Accepted: 15-09-2024
Published: 31-10-2024

Abstract: The development of the construction world is driven by the demands of meeting various needs, such as in this case study, namely the construction of the Bantul satpol PP Building to meet the needs of the legal apparatus. However, according to the United Nations Environtment Program in the Global Status Report for Buildings and Construction (2021) states that this development has a significant environmental impact, construction projects are responsible for 36% of energy consumption and 37% global CO_2 emissions by 2020. Therefore, this research aims of achieving Greenhouse Gas Emission (GHG) efficiency using the Life Cycle Assessment (LCA) method. Data analysis was applied through the Autodesk Revit program to get the material schedule and LCA approach within the scope of Cradle to Gate using ISO 14040 and 14044 guidelines. The structure of foundations, slabs, columns and beams became the object of research because the constituent materials in the form of concrete and steel are considered as CO_2 GHG contributors with the largest percentage, reaching 75% of the total emissions released (Luo et al., 2016). The analysis results show that the largest GHG estimate is located in the structural work of the Cradle to Gate scope which reaches 1,657,880.04 $KgCO_2eq$ with the most critical process unit which is the material production process unit. Thus, project construction management can look for the best alternatives related to material selection or methods in the material production process that can reduce GHG emissions. This research can be applied to create a sustainable construction.

Keywords: Construction Management, Greenhouse Gas Emissions, Life Cycle Assesment.

Introduction

Technological developments in the field of construction continue to be encouraged as a form of adjustment to the times that demand a large quantity of construction. Thus, creative solutions are needed to increase the effectiveness of cost, time and quality. One of the advanced technologies that is a creative solution in helping and encouraging the pace of improvement in the field of construction development is Building Information Modeling (BIM) (Zubair, 2024). Building Information Modeling (BIM) has become one of the promising developments in the field of construction and architecture in recent years (Prabhkaran et al., 2020). The use of BIM provides support for building programs, site analysis, orientation of buildings, building mass plans, and construction. The use of BIM is also used to answer the interests and problems in the construction sector which have been known as the triple constraints of time, cost, and quality (Toroxel, 2024). Thus, BIM is known as 5D, namely data, vector drawings, virtual coordination, schedule simulation, and cost estimation.

One analysis related to the environmental impact of a construction implementation is to use the Life Cycle Assessment (LCA) approach. LCA is a method to evaluate inputs, outputs, and potential environmental impacts in the life cycle of a product system. The impact reviewed start from the collection and processing of raw materials, manufacturing, use, maintenance, to the end of the building's operating period (Morsi et al., 2022).

Several studies have been conducted to examine LCA estimation. This research focuses on concrete structures. The consideration behind this research is the design of concrete structures which are considered to have large enough dimensions with the use of cement as a constituent of concrete material which is the largest contributor to GHG emissions. Therefore, it is necessary to consider concrete design by calculating the GHG emissions produced using the LCA approach as a benchmark for decision making. From this research, it is expected that the best alternative can be obtained for the selection of appropriate and efficient and optimal methods and materials so as to obtain greenhouse gas emission efficiency at the implementation stage of the Satpol PP Building Construction project in Bantul Regency.

Methodology

This research was conducted at the Satpol PP Building Construction Project in Bantul Regional Government Office Complex II, East Ring Road Manding St., Trirenggo, Bantul, D.I Yogyakarta, which has a building area of approximately 982 m^2 and a land area of 2.618 m^2 built with various types of rooms. However, this research is limited to certain structures in the Satpol PP Building Construction Project.

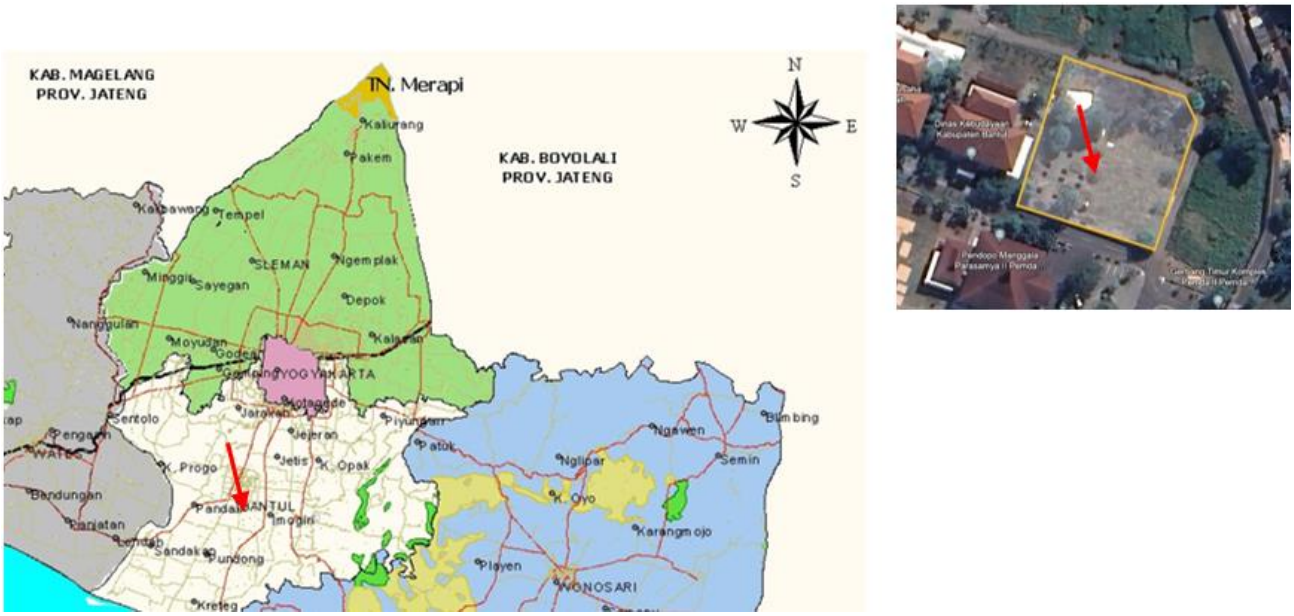

Figure 1. Research Location

The analysis method used in this research is to use the Building Information Modeling (BIM) methods with Autodesk Revit and Life Cycle Assessment (LCA) methods. The analysis in this research uses 5 stages, starting from a literature study to find the main and supporting data of the research such as as-built drawings and LCA database. After that, the data is inputted in Autodesk Revit to get the material schedule. The quantity take off from the material schedule is processed with the LCA method which produces an output of greenhouse gas emissions on the project according to the quantity take off, energy used, and total distance transportation. Finally, the recommendation stage is carried out which is the stage of delivering the results of the analysis and alternatives offered as a basis for consideration of the desired emission effectiveness. The following is a flow chart of the 5 stages above:

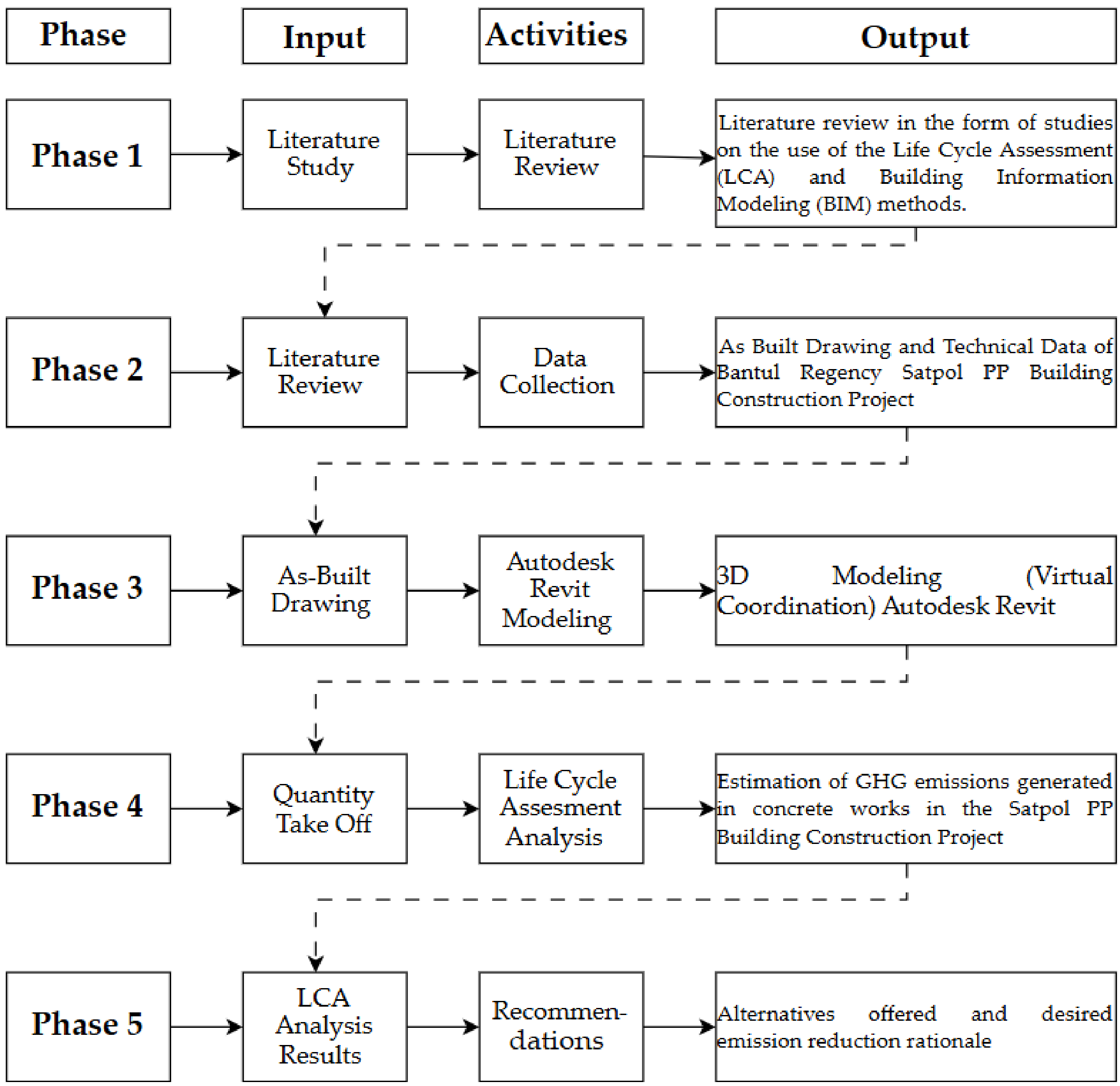

Figure 2. Research flow chart

Result and Discussion

Re-design

Author conducted a re-design based on data obtained from the project with the Building Information Modeling method using Autodesk Revit. The data used is in the form of As Built Drawing. The template used in Revit is a structural template. The following are the results of the 3D modeling re-design.

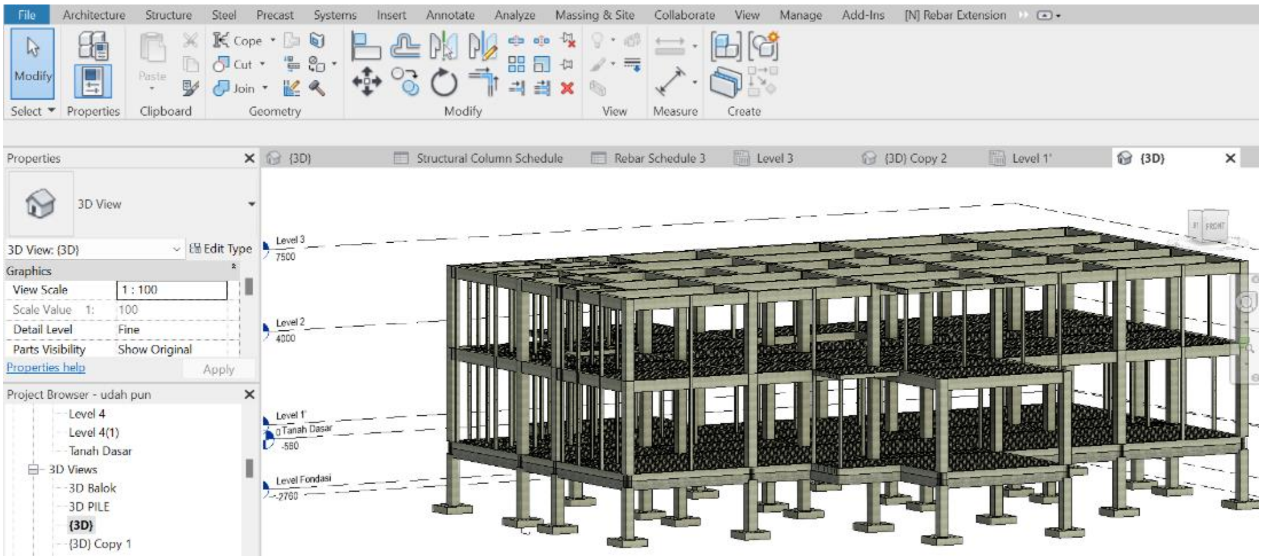

Figure 3. 3D Modeling View of Re-design based on As-built Drawing Data

Quantity take off

The final result of this modeling is a material schedule to obtain a Quantity Take Off (QTO) of structural work which will then be analyzed using LCA method to obtain an estimate of greenhouse gas emissions. The following figure is a display of one of the QTO's for the 2nd floor main beam work with a total concrete volume of 33,47 m^3

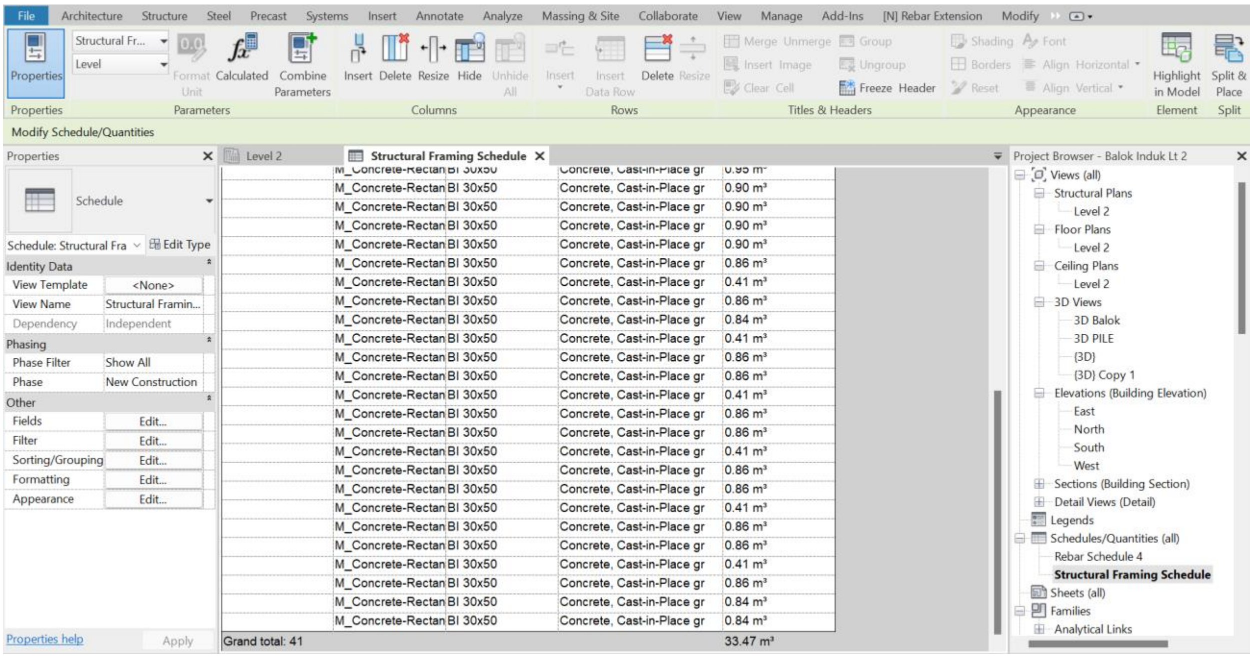

Figure 4. QTO Display Example of Re-design Result based on As-built Drawing Data

After making a material schedule of all structural works in the Bantul Satpol PP Building Construction Project, the following is a recapitulation of the QTO concrete and rebar obtained.

Table 1. Recapitulation of the Volume of Concrete (m^3) and Rebar (cm^3) of the Project's Structural Works

NO	Name	Concrete Volume (m3)	Rebar Volume (cm3)
	Foundation		
1	Structural Foundation Schedule Footplat + KP	12.19	266472.33
2	Structural Column Pedestal	9.15	190212.33
	1st Floor		
1	Structural Framing Schedule SLP	9.79	31565.02
2	Structural Framing Schedule SLS	40.14	368892.21
3	Structural Framing Schedule RB	0.71	10367.81
4	Structural Column Schedule	16.64	426821.23
5	Practical Column Schedule	3.11	74827.97
6	Structural Framing Schedule BL	0.25	5440.09
7	Structural Framing Schedule BB	0.73	9330.17
8	Structure Schedule BI	33.47	675820.69
9	Structure Schedule BA	13.8	294991.08
10	Floor Schedule	46.83	-
	2nd Floor		
1	Structural Framing Schedule BA	7.5	159491.96
2	Structural Framing Schedule BI	29.07	644298.61
3	Structural Framing Schedule RB	1.53	22086.75
4	Practical Column Schedule	2.22	50417.49
5	Structural Column Schedule	13.44	282973.68
6	Floor Schedule	48.51	837096.76
Total		**289.08**	**4351106.18**

the results of the reinforcement volume (m^3) and weight (Kg) used for each existing structure are as follows:

Table 2. Volume and Weight of the Reinforcement material

Structure	Diameter mm	Length mm	Length m	Specific Gravity Kg/m	Total Weight Kg	Volume m3
Footplate Foundation	D16	1342048.00	1342.05	1.58	2120.44	0.27
Pedestal Column	D16	782600.00	782.60	1.58	1236.51	0.16
	D10	491266.00	491.27	0.62	303.11	0.03

Structure	Diameter mm	Length mm	Length m	Specific Gravity Kg/m	Total Weight Kg	Volume m3
Structural Sloof (SLS)	D16	1392977.00	1392.98	1.58	2200.90	0.28
	D10	1302269.00	1302.27	0.62	803.50	0.09
Practical Sloof (SLP)	D10	299663.00	299.66	0.62	184.89	0.02
	D6	450796.00	450.80	0.22	100.08	0.01
Structural Column (KS)	D16	2983123.00	2983.12	1.58	4713.33	0.59
	D10	1657348.00	1657.35	0.62	1022.58	0.12
Practical Column (KP)	D10	1523660.00	1523.66	0.62	940.10	0.11
	D6	752989.00	752.99	0.22	167.16	0.02
Joist	D16	1713323.00	1713.32	1.58	2707.05	0.34
	D10	1612416.00	1612.42	0.62	994.86	0.11
Main Beam	D16	5181272.00	5181.27	1.58	8186.41	1.03
	D10	4110257.00	4110.26	0.62	2536.03	0.29
Floor Joist	D10	61824.00	61.82	0.62	38.15	0.00
	D6	46192.00	46.19	0.22	10.25	0.00
Ring Balk	D10	329964.00	329.96	0.62	203.59	0.02
	D6	395856.00	395.86	0.22	87.88	0.01
Divide Beam	D10	89585.00	89.59	0.62	55.27	0.01
	D6	130126.00	130.13	0.22	28.89	0.00
Floor	D10	11809692.00	11809.69	0.62	7286.58	0.84

Energy uses

After the quantity material data is complete, the next step that is needed calculating process of energy used, as well as mobilization data. The following table is the data that the author uses:

Table 3. Calculation of the Amount of Energy Used

Electricity Demand of Bantul Regency Satpol PP Building Construction Project				
Power	:	7700	Watt	
Electrical Energy	:	272	kWH	
Electrical Costs	:	IDR500,000.00		
Total cost of electricity used for construction	:		IDR3,500,000.00	
Total electrical energy used during construction	:		**1904**	**Kwh**

Water requirement of Bantul Regency Satpol PP Building Construction Project			
Water density in concrete	:	170	kg/m3
Concrete total volume	:	289.08	m3
Amount of water used	:	49143.6	kg
	:	**49143.6**	**litre**

Material Mobilization

The amount of greenhouse gas emissions is also determined based on the distance (S) and repetition of material mobilization. Therefore, the author needs to find data on the source of material (Quarry) used by the project to determine the distance of mobilization as shown in the following table:

Table 4. Calculation of Total Material Mobilization Distance (S)

Material	Source	Distance from Source to BP (KM)	Distance from BP to Site (km)	Total Distance (S) (km)
Cement	PT Surya Karya Setiabudi	24.7	19.3	44
Coarse Agregat	SKS Stone Crusher Gamping	2	19.3	21.3
Sand	Ex.Merapi	38	19.3	57.3
Fly Ash	PT Surya Karya Setiabudi	24.7	19.3	44
Admixture	PT Surya Karya Setiabudi	24.7	19.3	44
Water	SKS - PT. Surya Karya Setiabudi	0	0	0
Reinforcement	TB. Rizki Putra Makmur	0	27.8	27.8

Life cycle assessment analysis

The next step after all the required data such as material volume, amount of energy used, and material mobilization distance are available. Greenhouse Gas Emissions (GHG) can be calculated using the following formula:

$$\textit{GHG of Material Production Unit}\ \mathbf{(kgCO_2e) = V_{material}\ (Kg)\ x\ E_{factor}\ (KgCO_2e/Kg)}$$

$$\textit{GHG of Transportation Unit}\ \mathbf{(kgCO_2e) = W_{material}\ (Kg)\ x\ S\ (km)\ x\ FE_{truck}\ (KgCO_2e) x\ 2\ x\ Repetition}$$

GHG of Concrete Mixing Unit **($kgCO_2e$) = Time (h) x $E_{factor\ mixer}$ ($KgCO_2e/h$)**

GHG of Concrete Construction on Site Unit **($kgCO_2e$) = Time (h) x Tools E_{factor} ($KgCO_2e/h$)**

Emission Factor (E_{factor}) of tools and materials based on LCA database and ecoinvent database.

Tablel 5. Emissions Factor of material

No	Material	Emissions Factor (KgCO2e/kg)
1	Cement	1.0670
2	Agregat	0.0032
3	Reinforcement	2.0000
4	Additive	0.6900

Tablel 6. Emissions of truck 7.5 metric ton/1ton.km

Emissions Gas	Emissions Factor (KgCO2eq)
Carbon Dioxide	0.353

Tablel 7. Emissions of truck 16-32 metric ton/1ton.km

Emissions Gas	Emissions Factor (KgCO2eq)
Carbon Dioxide	0.119

The following are the Greenhouse Gas Emissions (GHG) of CO_2e generated of the structural construction of the Satpol PP Building Development Project, Bantul Regency, D.I Yogyakarta with the scope of Cradle to Gate resulting from the calculation of the LCA method.

Tablel 8. Recapitulation of GHG Emissions of Each Process Unit of Cradle to Gate Scope

No	**Unit Process**	**Stages**	**Emissions (Kg CO2e)**
1	Material Production Process	Aggregate Production	1,652,899.06
		Cement Production	
		Admixture Production	
		Fly Ash Production	
		Reinforcement Production	
2	Mobilization to the Batching Plan	Aggregate Mobilization	3,898.45
		Cement Mobilization	
		Admixture Mobilization	
		Fly Ash Mobilization	
3	Mixing in Batching Plan	Concrete Mixing	

No	Unit Process	Stages	Emissions (Kg CO2e)
4	Site Mobilization	Mobilization of Concrete from Batching Plan	
		Mobilization of Reinforcement Steel	
5	Construction Process on Site	Installation of Reinforcing Steel	1,082.52
		Concrete Casting	
Total			**1,657,880.04**

Alternative solutions to reduce emissions

From the calculations in the table above, it can be concluded that the material production process is the biggest greenhouse gas emitter. Therefore, to reduce emissions, it can be done by substituting materials using the least emitting materials to reduce or even replace materials or materials that have the greatest potential to produce emissions. For example, granite waste can be used as a substitute for cement. In addition, it can also be done by making careful calculations related to volume requirements so that there is no excessive production of materials so that emissions from the production process unit will be reduced.

Conclusion

Based on the research and data analysis that has been carried out, conclusions can be drawn that answer the existing problem formulation, as follows, based on the structural modeling using Autodesk Revit 3D BIM Method, the foundation, column, beam, and slab work resulted in concrete volumes of 12.19 m^3, 44.56 m^3, 136.99 m^3, and 95.34 m^3 respectively and rebar volumes of 266,472.33 cm^3, 1,025,252.7 cm^3, 2,222,284.39 cm^3, and 837,096.76 cm^3 respectively. The process unit of the construction project of the Satpol PP Building that produces CO_2 emissions with the scope of Cradle to Gate consists of 5 process units, namely Material Production, Mobilization (Transportation) to the Batching Plan, Concrete Mixing, mobilization (Transportation) to the Site, and the construction process.

The total amount of greenhouse emissions (Kg CO_2eq) analysis if the Cradle to Gate scope of the Satpol PP Building Construction Project is 1,657,880.04 Kg CO_2eq. Based on the results of data analysis and processing, it can be concluded that the most critical process unit for CO_2e emissions is the material production process unit with emission reaching 1,652,899.04 Kg CO_2eq.

References

2021 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION Towards a zero-emissions, efficient and resilient buildings and construction sector. (2021). www.globalabc.org.

Dixit, G., Misal, G., Gulkari, V., & Upadhye, K. (2013). FORMULATION AND EVALUATION OF POLYHERBAL GEL FOR ANTI-INFLAMMATORY ACTIVITY. IJPSR, 4(3). www.ijpsr.com

Forth, K. (2023). Interactive visualization of uncertain embodied GHG emissions for design decision support in early stages using open BIM. *Life-Cycle of Structures and Infrastructure Systems - Proceedings of the 8th International Symposium on Life-Cycle Civil Engineering, IALCCE 2023*, 3634–3641. https://doi.org/10.1201/9781003323020-445

Gao, Y. (2024). Multi-information integration-based life cycle analysis of greenhouse gas emissions for prefabricated construction: A case study of Shenzhen. *Environmental Impact Assessment Review*, *104*. https://doi.org/10.1016/j.eiar.2023.107330

Harjanto, T. R., Fahrurrozi, M., & Made Bendiyasa, I. (2012). Life Cycle Assessment Pabrik Semen PT Holcim Indonesia Tbk. Pabrik Cilacap: Komparasi antara Bahan Bakar Batubara dengan Biomassa. In Jurnal Rekayasa Proses (Vol. 6, Issue 2).

Hermawan, Farida Marzuki, P., Abduh, M., & Driejana, R. (2013). PERAN LIFE CYCLE ANALYSIS (LCA) PADA MATERIAL KONSTRUKSI DALAM UPAYA MENURUNKAN DAMPAK EMISI KARBON DIOKSIDA PADA EFEK GAS RUMAH KACA (031K). In Universitas Sebelas Maret (UNS)-Surakarta (Vol. 7, Issue 7). www.vtt.fi

Holzer, D. (2015). BIM and Parametric Design in Academia and Practice: The Changing Context of Knowledge Acquisition and Application in the Digital Age. International Journal of Architectural Computing, 13, 65–82. https://doi.org/10.1260/1478-0771.13.1.65

KUMANAYAKE, R., & LUO, H. (2018). Life cycle carbon emission assessment of a multi-purpose university building: A case study of Sri Lanka. Frontiers of Engineering Management, 0(0), 0. https://doi.org/10.15302/j-fem-2018055

Luo, Z., Yang, L., & Liu, J. (2016). Embodied carbon emissions of office building: A case study of China's 78 office buildings. Building and Environment, 95, 365–371. https://doi.org/10.1016/J.BUILDENV.2015.09.018

Mohebbi, G. (2021). The role of embodied carbon databases in the accuracy of life cycle assessment (LCA) calculations for the embodied carbon of buildings. *Sustainability (Switzerland)*, *13*(14). https://doi.org/10.3390/su13147988

Morsi, D. M. A., Ismaeel, W. S. E., Ehab, A., & Othman, A. A. E. (2022). BIM-based life cycle assessment for different structural system scenarios of a residential building. Ain Shams Engineering Journal, 13(6). https://doi.org/10.1016/j.asej.2022.101802

Prabhakaran, A., Mahamadu, A.-M., Mahdjoubi, L., & Manu, P. (2020). An Approach for Integrating Mixed Reality into BIM for Early Stage Design Coordination. MATEC Web of Conferences, 312, 04001. https://doi.org/10.1051/matecconf/202031204001

Rahla Rabia, M. P., Kumar, D. S., Farooq, J., & Pachauri, R. K. (2021). Applications of Building Information Modeling for COVID-19 spread assessment due to the organization of building artifacts. In Data Science for COVID-19: Volume 2: Societal and Medical Perspectives (pp. 319–333). Elsevier. https://doi.org/10.1016/B978-0-323-90769-9.00009-8

Ramlan, M. (2002). PEMANASAN GLOBAL (GLOBAL WARMING).

SNI-2847-2019-Persyaratan-Beton-Struktural-Untuk-Bangunan-Gedung-1 (1). (n.d.).

Sun, C., Xu, H., Wan, D., & Li, Y. (2021). Building Information Modeling Application Maturity Model (BIM-AMM) from the Viewpoint of Construction Project. Advances in Civil Engineering, 2021. https://doi.org/10.1155/2021/6684031

Toroxel, J. L. (2024). A Review of Passive Solar Heating and Cooling Technologies Based on Bioclimatic and Vernacular Architecture. *Energies*, *17*(5). https://doi.org/10.3390/en17051006

Zubair, M. U. (2024). BIM- and GIS-Based Life-Cycle-Assessment Framework for Enhancing Eco Efficiency and Sustainability in the Construction Sector. *Buildings*, *14*(2). https://doi.org/10.3390/buildings14020360