JURNAL MULTIDISIPLIN MADANI (MUDIMA)

Homepage: https://mryformosapublisher.org/index.php/mudima

ISSN: 2808-5639 (Online)

Research Article

Volume 5, No 4, April (2025)	DOI: https://doi.org/10.55927/mudima.v5i4.154	Page: 295-304

Optimization of Steel Column Design with Tekla Structures to Minimize Embodied Carbon

Fardi Kalumata[1*], Hendrie Joudie Palar[2], Fandel Maluw[3]

Politeknik Negeri Manado

Corresponding Author: Fardi Kalumata ardhykalumata23@gmail.com

ARTICLE INFO

Keywords: Design Optimization, Tekla Structures, Embodied Carbon

Received : *5 February*
Revised : *20 March*
Accepted : *22 April*

ABSTRACT

The construction sector is one of the largest greenhouse gas contributors in the world. The use of raw materials as building materials is the main cause of carbon emissions in the construction industry. The use of steel materials has become very popular because it can be associated with a number of qualities, including its extraordinary durability, resistance to pressure, and flexibility. This is the main cause of steel materials being used massively in construction projects. If this continues for a long time, it will result in increasingly severe global warming. Therefore, a very detailed analysis and calculation are needed regarding the relationship between steel weight, carbon content, and structural strength so that, in addition to being structurally strong, it can be efficient in weight and very minimal in the carbon value released during the work process and the life of the building. Tekla Structures software is one of the software programs that can be used for the above analysis needs, the ultimate goal of which is to reduce carbon emissions. Three (3) different cross-section sizes have been examined using structural analysis, and calculations have been made on the carbon content that can be optimized for the material: H 400.400.13.2, 350.350.10.16, and 300.300.10.15. This study has successfully determined that the column with the size H 300.300.10.15 produces a carbon mass of 629,288.00 kg. (kg CO2e). With the smallest carbon content value and the carbon presentation in the material of 66.23%, the column cross-section with the size H 300.300.10.15 is recommended for use as a column structure cross-section

INTRODUCTION

1. Background on Embodied Carbon in Construction

Embodied carbon in construction refers to the carbon dioxide emissions associated with the manufacturing, transportation, and construction of building materials. As the construction industry continues to grow, the importance of addressing embodied carbon becomes increasingly urgent. With buildings accounting for a significant portion of global greenhouse gas emissions, it is crucial for architects, engineers, and developers to consider the environmental impact of their design choices. In this paper, we will explore the current state of embodied carbon in construction and discuss potential strategies for reducing emissions in the built environment. By implementing sustainable practices such as using low-carbon materials, optimizing building designs for energy efficiency, and incorporating renewable energy sources, stakeholders in the construction industry can significantly reduce the carbon footprint of their projects. Additionally, advocating for more stringent regulations and standards related to embodied carbon can help drive positive change in the industry. Ultimately, by taking proactive steps to address embodied carbon, professionals in the construction sector can play a crucial role in mitigating the effects of climate change and creating a more sustainable built environment for future generations.

2. Importance of Optimizing Steel Column Design to Minimize Embodied Carbon

One key aspect of reducing embedded carbon in construction is optimizing the design of steel columns. Steel is a commonly used material in building construction due to its strength and versatility, but it also has a high carbon footprint. By carefully designing steel columns to minimize material waste and maximize efficiency, architects and engineers can significantly reduce the embodied carbon of a building. This not only helps to lower the environmental impact of the construction industry but also contributes to the overall sustainability of the built environment. Furthermore, incorporating recycled steel or using alternative materials like timber can also help lower the carbon footprint of a building. By considering the entire lifecycle of a structure and making conscious choices during the design phase, construction professionals can make a significant impact on reducing embodied carbon. Ultimately, the goal is to create buildings that not only meet the needs of the present but also consider the needs of future generations by prioritizing sustainability and environmental responsibility.

3. Overview of Tekla Structures Designer Software

One software that can aid in optimizing the design of steel columns and reducing embodied carbon in construction is the Tekla Structures Designer software. This advanced building information modeling (BIM) software allows architects and engineers to create detailed 3D models of structures, including steel columns, and analyze their performance and environmental impact. By utilizing Tekla Structures Desainer, professionals can make informed decisions about the design and construction of steel columns, ultimately leading to more sustainable building practices. Additionally, the software offers features such as clash detection, which helps identify potential conflicts in the design before construction begins, saving time and resources. With Tekla Structures Designer, users can also easily collaborate with other team members, share models, and streamline the entire design process. Overall, this software plays a crucial role in promoting sustainable building practices and reducing the carbon footprint of construction projects.

METHODS

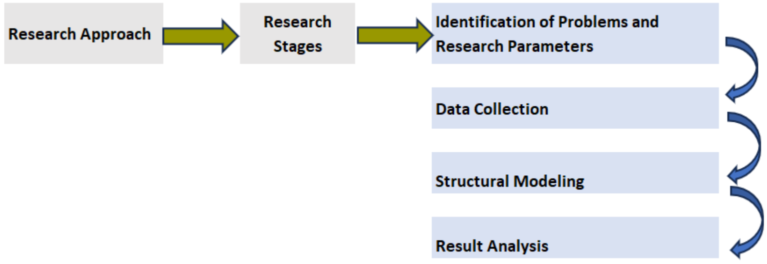

Figure 1. Flowchart Research

Figure 1 is an explanation of the research stages that will be carried out to obtain results on how much carbon content is contained in steel in a building structure. Figure number 1 is sourced from the author himself.

1. **Research Approach**
   This research uses a quantitative approach with software-based simulation to optimize the design of a more efficient and environmentally friendly steel column cross-section. The analysis is carried out by comparing various design parameters to the resulting carbon content.
2. **Research Stages**
   Literature Study on the Influence of Various Factors on Carbon Emissions in the Steelmaking Process. Basic theory of steel structures and carbon content in construction materials. Steel structure design optimization method. Tekla Structural Designer software features and capabilities.
3. **Identification of Problems and Research Parameters**
   Determine the type of steel and carbon content to be analyzed.
   Determine design parameters, such as cross-section dimensions, applied loads, and material strength limitations.
   Determine optimization targets (e.g., steel weight reduction and carbon content).
4. **Data Collection**
   Steel material technical data (e.g., low carbon steel specifications).
   Structural load data in accordance with design standards (SNI, AISC, or Eurocode).
5. **Structural Modeling**
   Create a steel column structure model using Tekla Structural Designer.
   Enter design parameters and loading according to the data that has been collected.
6. **Result Analysis**
   Comparing the simulation results of the steel cross-section to the resulting carbon content. Evaluating the efficiency of the cross-section based on strength, stability, and carbon content reduction.

Explain your methodologies in this chapter. You should explain your research instruments, data collection processes, data analysis processes or hypothesis testing processes, and data display processes.

RESULTS AND DISCUSSION

1. Data Material

- Structure Material : Steel
- Structure Frame Type : H Column Structure 400.400.13.21
- Steel Beam I Wide Flange 300.200.
- Steel Beam I Wide Flange 450.300
- Steel Beam I Wide Flange 600.300
- Metal Deck Floor
- Slab Thickness 150 mm metal deck floor Thickness 1.2 mm
- Quality Steel Profile: BJ 41 (410 Mpa)
- Profile Steel Quality (Fu): 410 Mpa
- Profile Steel Quality (Fy): 250 MPa

2. Loading Method

The planning of the loading on this structure is based on the Indonesian Loading Regulation for Buildings (PPIUG 1983) and SNI 03-1729-2019. The combination of factored loads used in the

strength design method based on SNI 1727 2013 concerning the minimum load for the design of buildings and other structures includes:
1. Combination of 1 U = 1.4 D
2. Combination of 2 U = 1.2 D + 1.6 L + 0.5 (Lr or R)
3. Combination of 3 U = 1.2 D + 1.6 (Lr or R) + 1.0 (L or 0.5 W)
4. Combination of 4 U = 1.2 DL + 1.0 W + 1.0 LL + 0.5 (Lr or R)
5. Combination of 5 U = 1.2 D + 1.0 E + L
6. Combination of 6 U = 0.9 D + 1.0 W
7. Combination of 7 U = 0.9 D + 1.0 E

3. Structural Strength Modeling and Analysis of Embodied Carbon

Building structure modeling is made using Tekla structure designer software version 24.01.45 with the following modeling steps:

• Modeling Grids, and Levels in accordance with building plans
• Cross-sectional settings, beams, columns, plates,
• Setting material
• Structure modeling and load input
• Combination load input
• Set Analysis – then Run.

To analyze the structural strength and Carbon Embodied on each structural element, it can be seen through the review menu, as shown in the figure 2 below:

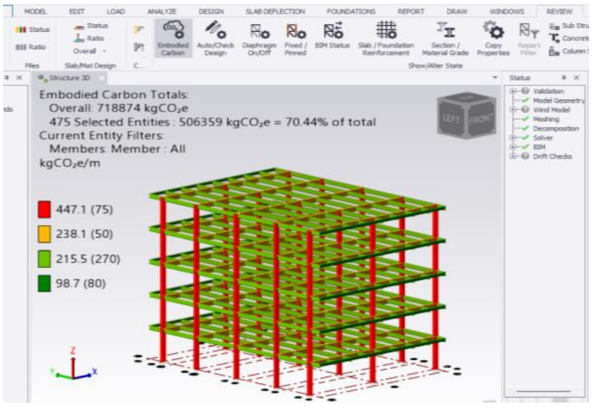

Figure 2. Carbon Embodied on Each Structural Element
Source: Based on Calculation Results

Based on calculation results in figure 2 (two) [12], the carbon content within the structure produces 71,887.4 kgCO2e with a presentation of 70.44%.

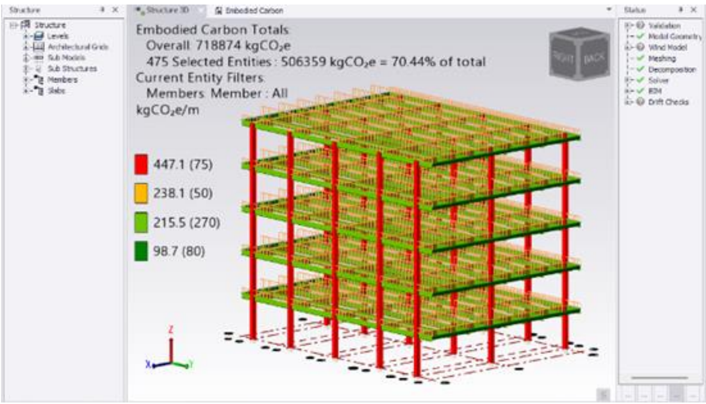

Figure 3. Total Carbon Embodied in A 5-Storey Building
Source: Based on Calculation Results

Based on calculation results in figure 3 (three) [12], the carbon content within the structure produces 71,887.4 kgCO2e with a presentation of 70.44%, with load maksimum combination

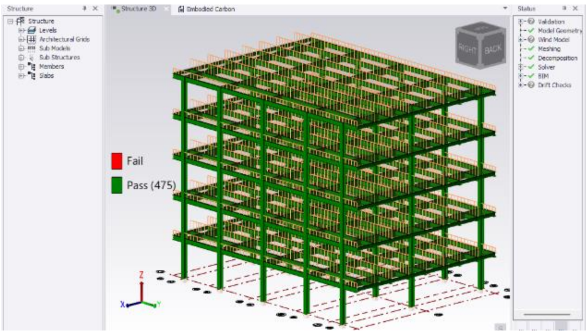

Figure 4. The Results of the Structure Analysis Showed
Source: Based on Calculation Results

Based on calculation results in figure 4 (four) [12], the carbon content within the structure produces 71,887.4 kg CO2e with a presentation of 70.44%, and structre are stable with pass 475 element.

4. Results of Carbon Content Calculation in Building Structural Elements

After the run and analysis, the details of the carbon content results were obtained as follows [5]:

Table 1. Embodied Carbon Overview by Level

Reference	Level	Embodied Carbon Mass [$KgCO_{2e}$]	Floored Area m^2	Embodied Carbon Mass Per Floored Area [KgCO2e]
St .5	20	143775.00	459	313.2
St. 4	16	143775.00	459	313.2
St. 3	12	143775.00	459	313.2
St. 2	8	143775.00	459	313.2
St. 1	4	143775.00	459	313.2
Total		718875.00	2295.00	1566.00

Source: Based on Calculation Results

Table 1. Embodied Carbon Overview by Construction Type

Construction Tye	Embodied Carbon Mass [KgCO2e]
Steel Beams Rolled Non - Composite	372217
Composite Slabs	212515
Steel Columns Rolled	134142
Total	718874

Source: Based on Calculation Results

Table 2. Embodied Carbon Overview by Construction Type & Material

Construction Type	Material	Quantity	Unit	Carbon Factor	Embodied Carbon Mass [KgCO2e]
Steel Beams Rolled Non - Composite	Steel	235580.40	Kg	Global Rolled Open Sections (1.580)	372.217
Steel Columns Rolled	Steel	84900.00	Kg	Globak Rolled Open Section (1.580)	134.142
Composite Slabs	Concrete	691465.78	Kg	Cast-in-place, unreinforced generic (0.150)	103.720
Composite Slabs	Metal Deck	36977.04	Kg	Steel Deck (2.740)	101.317
Composite Slabs	Reinforcement Mesh Class Gr. 65	2991.11	Kg	Reinforcement Mesh (2.500)	7.478
Steel Column Rolled	Coating	721.9	m^2		
Steel Beams Rolled Non – Composite	Coating	3587.0	m^2		
Composite Slabs	Floor Finish	2295.0	m^2		
Total					718.874

Source: Based on Calculation Results

After analyzing 3 types of steel cross-sections for columns, the results obtained that the carbon content in each different element can be seen in the following figure below:

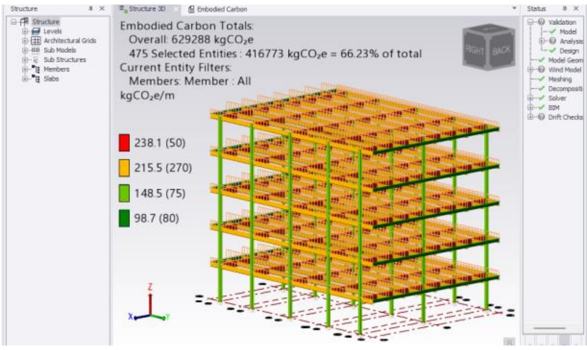

Figure 5. Carbon Embodied H 300.300.94

Source: Based on Calculation Results

Based on calculation results, this figure 5 (five) [12] show the presentation 66.23 % of carbon embodied in structure element, with 416.773 kgCO2e, using steel column H 300.300, with mass 94 kg / m.

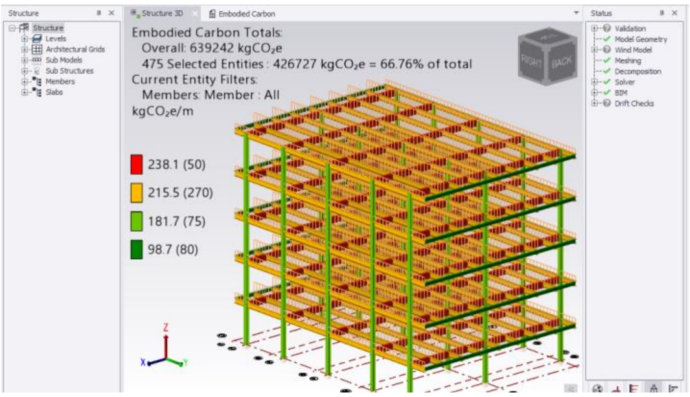

Figure 6. Carbon Embodied H 350.350.115

Source: Based on Calculation Results

Based on calculation results this figure 6 (six) [12] show the presentation 66.76 %, of carbon embodied in structure element, with 426.727 kgCO2e, using steel column H 350.350, with mass 115 kg / m

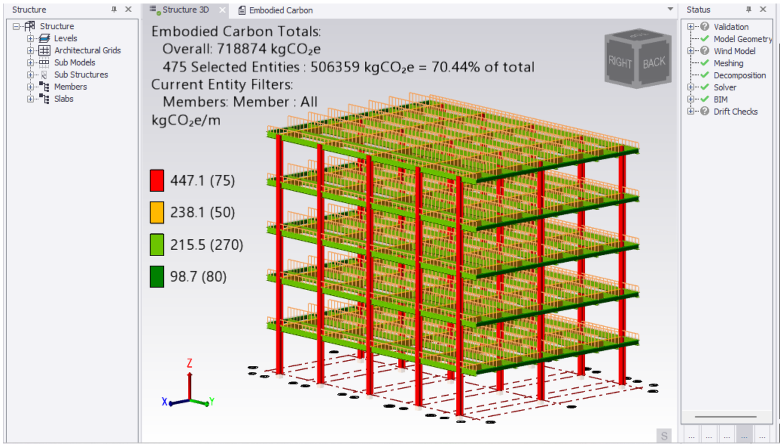

Figure 7. Carbon Embodied H 400.400.13.21

Source: Based on Calculation Results

Based on calculation results this figure 7 (seven)[12] show the presentation 70.44 %, of carbon embodied in structure element, with 506.359 kgCO2e, using steel column H 400.400, 13,21 and this configuration are the most weigh and most carbon embodied than others.

5. The Relationship of Contained Carbon, Steel Weight, and Steel Column Cross-Section

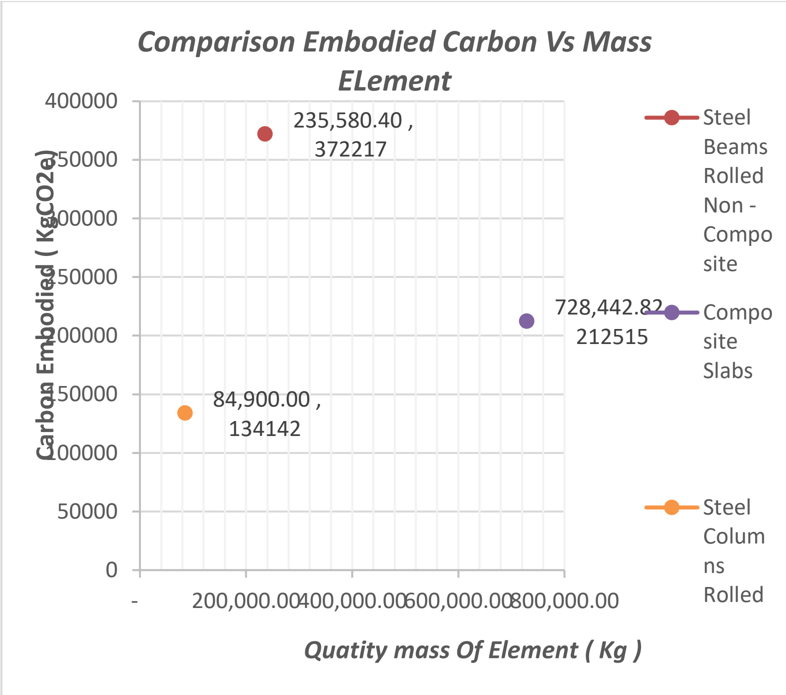

Figure 8. Carbon Embodied Comparison

Source: Based on Calculation Results

Based on the results of the analysis using the Tekla Strutkur designer software, the carbon analysis for each strutkur element can be seen in the following:

Table 3. Carbon Analysis Result

Type Of Steel Column	Construction Type			Total Embodied Carbon Mass [KgCO2e]	Precentase (%) Carbon Embodied in Structure
	Steel Beams Rolled Non – Composite	Composite Slabs	Steel Columns Rolled		
H 400.400.13.21	372,217.00	212,515.00	134,142.00	718,874.00	70.44
H 350.350.10.16	372,217.00	212,515.00	54,510.00	639,242.00	66.76
H 300.300.10.15	**372,217.00**	**212,515.00**	**44,556.00**	**629,288.00**	**66.23**

Source: Based on Calculation Results

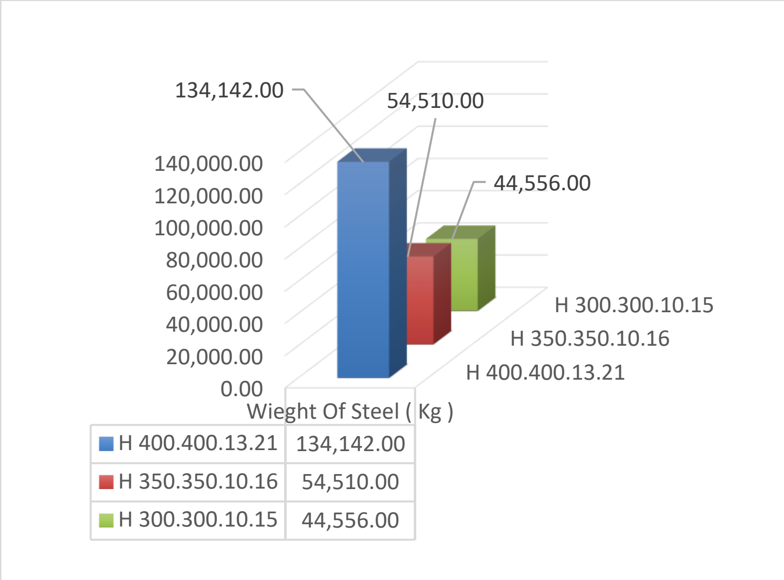

Figure 9. Weight of Steel Each Column Type
Source: Based on Calculation Results

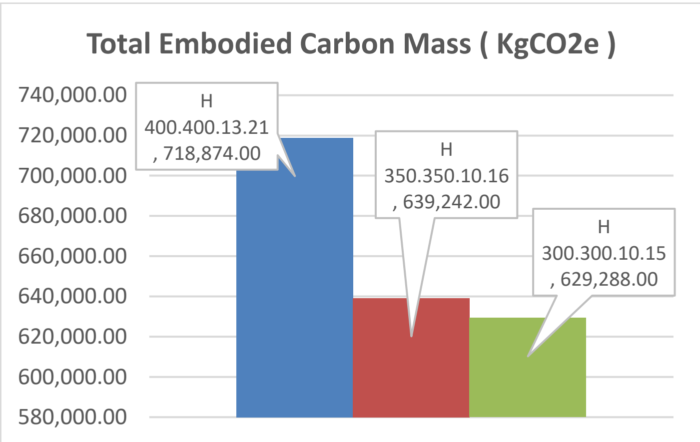

Figure 10. Total Embodied Carbon Mass
Source: Based on Calculation Results

CONCLUSION

Column with size H 300.300.10.15 produces 629,288.00 kg Embodied Carbon Mass [kgCO2e], column with size H 350.350.10.16 produces 639,242.00 kg Embodied Carbon Mass [kgCO2e] and a column with size H 400.400.13.21 produces 718,874.00 kg Embodied Carbon Mass [kgCO2e]. With the smallest carbon content value and a carbon presentation in the material of 66.23%, the column cross section with size H 300.300.10.15 is recommended to be used as the column structure cross section.

REFERENCES

A. Akbarnezhad and J. Xiao, "Estimation and Minimization of Embodied Carbon of Buildings : A Review," no. I, pp. 1–24, 2017, doi: 10.3390/buildings7010005.

A. Akbarnezhad and Z. S. M. Nadoushani, "Estimating the Costs , Energy Use and Carbon Emissions of Concrete Recycling Using Building Information Modelling," no. Isarc, 2014.

A. Hasanbeigi, "Steel Climate Impact," no. April, 2022, [Online]. Available: https://www.globalefficiencyintel.com

A. Primasetra, D. Larasati, S. Wonorahardjo, and I. Sudradjat, “SOFTWARE APPLICATION FOR EMBODIED ENERGY BUILDING CALCULATION : A REVIEW,” vol. 49, no. 1, pp. 53–64, 2022, doi: 10.9744/dimensi.49.1.53-64.

A. Syukri, H. Alexander, I. Agus, A. Akbar, and R. Bukhari, “Quantity Optimization of Structure Works with Building Information modeling for Politeknik Negeri Padang ’ s Integrated Technology Laboratory Building Design”, doi: 10.4108/eai.21-9-2023.2342895.

C. S. Poon, A. Yu, and L. Jaillon, “Reducing building waste at construction sites in Hong Kong,” Constr. Manag. Econ., vol. 22, pp. 461–470, Feb. 2004, doi: 10.1080/0144619042000202816.

F. Kalumata, J. Tanijaya, and E. R. Bungin, “ANALYSIS OF THE IMPLEMENTATION OF BUILDING INFORMATION MODELING (BIM) IN THE ACCELERATION OF BUILDING CONSTRUCTION MANADO STUDENTS’DORMITORY,” in International Conference on Engineering & Appliance Science and International Conference on Social Science (ICEA & ICSS) Proceedings, 2024.

Figure 1 Flowchart research

Figure 2 – 10 The result of calculation using Tekla Structure Designer Software

G. Sandin, G. M. Peters, and M. Svanström, “Life cycle assessment of construction materials: the influence of assumptions in end-of-life modelling,” Int. J. Life Cycle Assess., vol. 19, no. 4, pp. 723–731, 2014, doi: 10.1007/s11367-013-0686-x.

P. I. Christian, “ANALYSIS OF THE IMPLEMENTATION OF BUILDING INFORMATION MODELING (BIM) IN THE ACCELERATION OF BUILDING CONSTRUCTION MANADO STUDENTS’ DORMITORY Fardi Kalumata 1 , Jonie Tanijaya 2 , Erni Rantebungin 3,” vol. c, pp. 9–19.

S. Selvaraj and T.-M. Chan, “Recommendations for Implementing Circular Economy in Construction: Direct Reuse of Steel Structures,” J. Constr. Steel Res., vol. 214, p. 108439, 2024, doi: https://doi.org/10.1016/j.jcsr.2023.108439.

Table 1 – 4 The result of calculation using Tekla Structure Designer Software

U. Ali, R. Azam, M. Shakeel, M. Adil, and M. R. Riaz, “A practical tool for structural design optimization of steel frames: development and application for parametric analysis,” Innov. Infrastruct. Solut., vol. 9, no. 1, p. 3, 2023, doi: 10.1007/s41062-023-01314-3.

X. Su and X. Zhang, “A detailed analysis of the embodied energy and carbon emissions of steel-construction residential buildings in China,” Energy Build., vol. 119, pp. 323–330, 2016, doi: https://doi.org/10.1016/j.enbuild.2016.03.070.