JURNAL TEKNIK
Volume Volume 23, No. 2, Desember 2025
P-ISSN : 1693-6191 E-ISSN : 2715-7660
DOI : https://doi.org/10.37031/jt.v23i2.686

Comparative Analysis of Columns Ratio on Structural Performance and Cost Efficiency

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Abstract

Planning is crucial in construction as it can significantly reduce costs by aligning structural design with requirements while minimizing excess. This study evaluates the structural performance of columns with different shapes and dimensions, utilizing data from the construction site and Indonesian National Standards (SNI). The analysis reveals that square-shaped columns, with a cross-section ratio close to 1, require less material than rectangular columns, with a 17.35% lower concrete volume and a 23.37% smaller formwork area. However, the reinforcement needed for square columns is 6.38% higher. Overall, square columns lead to a 15.42% reduction in production costs. This also results in lower cement consumption, contributing to decreased CO_2 emissions—Design B using 856.32 kg (18.52%) less cement than Design A. The results support the principles of the Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). These findings align with the Sustainable Development Goals (SDGs), emphasizing the importance of sustainability alongside cost efficiency in structural planning.

Keywords: *Column dimension, Column shape, Cost efficiency, Structural performance, SDGs*

Diterima: Oktober 2025
Disetujui: November 2025
Dipublikasi: Desember 2025

Introduction

Civil engineering is a field that studies the planning, construction, maintenance, and repair of various types of infrastructure. The planning stage is important because a building must be able to bear loads according to its function (Rahmanto et al., 2023). Good planning can also reduce construction costs because the structural design results match the requirements and are not excessive. (Mei & Wang, 2021; Rady et al., 2022) Based on previous studies, cost savings from design optimization can reach 12.3% and 21% (Negrin et al., 2021; Zhang & Zhang, 2023).

Effective planning also contributes to addressing environmental issues. Construction activities—including material production, land clearing, equipment use, and others—generate large amounts of carbon dioxide released into the atmosphere (Akinyemi et al., 2017; Jackson, 2020). Global warming caused by carbon dioxide leads to rising earth temperatures, melting ice at the poles, acid rain, and extreme weather (Author, 2021). One example is the cement production process. According to data, every 1 ton of cement produced generates almost 1 ton of carbon dioxide (Fayomi et al., 2019; Soomro et al., 2023). Global cement production increased from 2 billion tons in 2003 to 4 billion tons in 2013. In the last decade, production has not increased significantly, but it has remained high at around 4 billion tons annually

(Ritchie & Rosado, 2025). This number means that about 4 billion tons of carbon dioxide are released into the atmosphere every year. Therefore, good planning can help reduce material use and the resulting negative impacts.

In practice, the planning process involves collaboration between engineers and architects to produce working drawings according to the needs and requests of building owners (Serag-Eldin, 2010). One of the common challenges is the demand for aesthetics, which may not align with the principle of demand vs. capacity in structural planning. For example, column dimensions wider than wall thickness can cause columns to extend beyond the wall, which may interfere with the view or the placement of furniture. Another example is minimizing the number of columns to make a space appear more spacious. Such requests can be realized, but they require high-quality materials to maintain small dimensions, which increases construction costs.

Based on these problems, building structural planning must consider material efficiency while also meeting functional and aesthetic requirements. This article aims to analyze the influence of shape, dimensions, and configuration of two-story residential structures on material efficiency and the fulfillment of the demand vs. capacity ratio. The study begins with data collection and planning using computer software. The design results are then analyzed to determine the material volume requirements.

Method

Data are required at the planning stage. The data were collected based on the existing conditions of the construction site, information from Indonesian National Standards (SNI), and other supporting sources. The data used in this study and their sources are described in the following sections.

Building dimensional data were obtained from the architectural drawings. The house has a width of 8.2 m and a length of 19.5 m. It consists of two floors, with the first-floor elevation at +3.0 m and the second-floor elevation at +6.0 m. Figure 1-2 shows the building section.

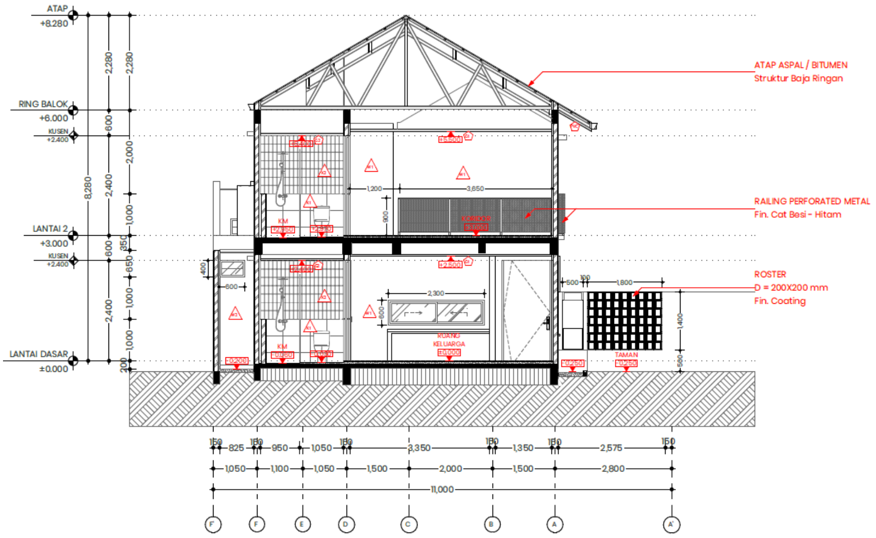

Figure 1. Section drawing of the building

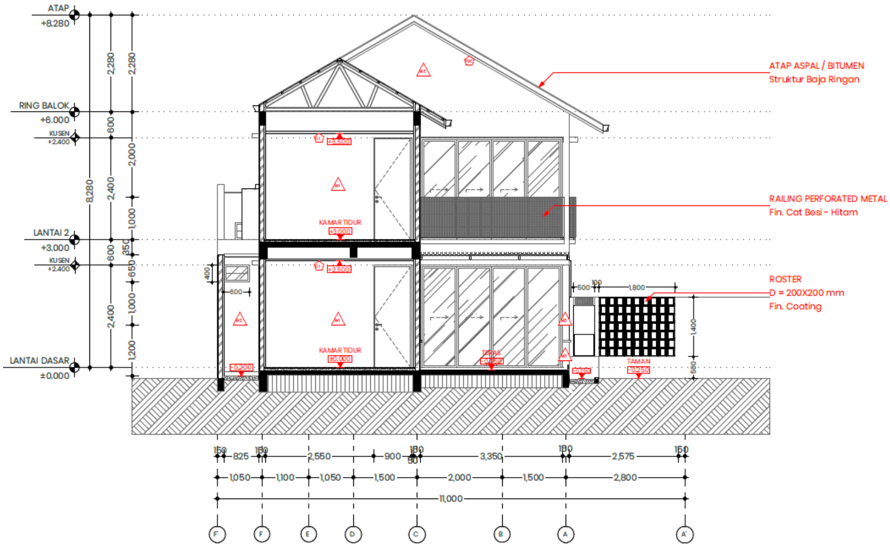

Figure 2. Section drawing of the building

Material data were adjusted to local needs and availability. The compressive strength of concrete used for the entire structure was 20 MPa. The quality of the steel materials is shown in Table 1.

Table 1. Material properties

Material	Quality	Tensile Strength (MPa)
Transversal Steel	BjTS-28	280
Longitudinal Steel for Slab, Beam, and Foundation	BjTS-28	280
Longitudinal Steel for Column	BjTS-42	420
Wiremash Steel	U-50	500
Floor Deck	-	550

Live load data were taken from Table 4.3.1 in SNI 1727:2020. The live load for all rooms, except stairs, was 1.92 kN/m², while the roof (not intended for occupancy) was 0.96 kN/m². Dead loads included the self-weight of the structure, with a density of 2400 kg/m³ for concrete and 7850 kg/m³ for steel. The wall load was calculated based on Table C3.1-1 in SNI 1727:2020, which is 2.805 kN/m² for a wall thickness of 15 cm, plus 0.24 kN/m² for one side of plaster and cement, giving a total of 9.855 kN/m after multiplying by the building height. Additional dead loads, such as floor finishes, ceilings, mechanical, electrical, and plumbing works, were assumed to be 0.76 kN/m². The load combinations used followed SNI 1727:2020, Section 2.3.1.

Earthquake loads were calculated based on SNI 1726:2019. All the relevant data are presented in Table 2.

Table 2. Data for earthquake design

Parameters	Result	Source/formula
Risk categories	II	SNI 1726:2019, Table 3
Building priority factors, I_e	1.0	SNI 1726:2019, table 4
Site classification	Medium soil (SD)	Existing conditions
Acceleration of bedrock in short periods, S_s	0.8883 g	https://rsa.ciptakarya.pu.go.id/2021/ based on building location
Bedrock acceleration at a period of 1 second, S_1	0.4191 g	
The site coefficient for a short period is at a period of 0.2 seconds, F_a	1.1894	SNI 1726:2019, Table 6
Site coefficient for long periods (at 1-second periods), F_v	2.3618	SNI 1726:2019, Table 7
Acceleration of spectral response in short periods, 5 percent attenuation, S_{DS}	0.7043 g	$2/3 * F_a * S_s$
Spectral response acceleration in 1 second period, 5 percent attenuation, S_{D1}	0.6599 g	$2/3*F_V*S_1$
T_s	0.9369 second	S_{DS}/S_{D1}
T_0	0.1874 second	$0.2 * T_s$
Response Modification Coefficient, R	3	SNI 1726:2019, Table 12
Strong Factor Over System, Ω_0	3	
Deflection Enlargement Factor, C_d	2.5	
C_u	1.4	SNI 1726:2019, table 17
C_t	0.0466	SNI 1726:2019, Table 18
X	0.9	SNI 1726:2019, Table 18
Building height, h	6 meters	Data from construction drawing
The fundamental period of the approach, T_a	0.2337 second	$C_t * h^x$
Upper period limit, T_{max}	0.3270 second	C_u*T_a
Long period, T_L	20 seconds	SNI 1726:2019, picture 20
C_{smax}	0.9411	$S_{D1}/(T_a * (R/I_e))$
C_{smin}	0.0310	$0.044 * S_{DS} * I_e$
C_s	0.2348	$S_{DS}/(R/I_e)$

Safety factors in the design followed SNI 2847:2019. According to Table 21.2.2, the flexural reduction factor ranges between 0.65 and 0.9, while the shear reduction factor, based on Section 12.5.3.2, is 0.75.

After all the data were collected, structural modelling was carried out using computer software (Figure 3) in accordance with the data in Tables 1–3. The resulting ultimate moment, ultimate shear force, and ultimate torsion were then used to calculate the required structural dimensions and reinforcement configurations.

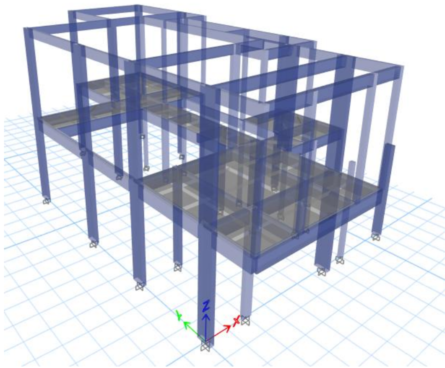

Figure 3. Structural modelling of the building

Result and Discussion

Result

Based on the load outputs from the software, a trial-and-error procedure was used to determine beam and column dimensions and reinforcement configurations that satisfy the design demands. Figures 4–6 illustrate the beam and column layout for Design A, while Figures 7–9 show the layout for Design B. Tables 4 and 5 summarize the dimensions and reinforcement configurations for the first design (Design A), in which the column widths do not exceed 150 mm. Tables 6 and 7 present the second design (Design B), which uses columns 200 mm wide, exceeding the wall thickness. The beam dimensions are identical in Designs A and B; however, the reinforcement configurations differ.

Table 4. Beam dimension and configuration for Design A

Name	Dimension (mm)		Area	Bending reinforcement		Shear reinforcement	Torsion reinforcement
	Width	Depth		Top	Bottom		
B1 Beam	200	400	Support	3 D13	3 D13	Ø10-100 mm	2 Ø10
			Midspan	3 D13	3 D13	Ø10-200 mm	2 Ø10
B2 Beam	200	400	Support	4 D13	3 D13	Ø10-75 mm	2 Ø10
			Midspan	3 D13	4 D13	Ø10-200 mm	2 Ø10

B3 Beam	150	350	Support	2 D16	2 D16	Ø10-150 mm	-
			Midspan	2 D16	2 D16	Ø10-200 mm	-
B4 Beam	150	400	Support	3 D13	3 D13	Ø10-150 mm	2 Ø10
			Midspan	3 D13	3 D13	Ø10-200 mm	2 Ø10

Table 5. Column dimension and configuration for Design A

Name	Dimension (mm)		Bending reinforcement	Shear reinforcement	
	X axis	Y axis		X axis	And axis
K1 Column	150	500	10 D13	2 Ø10-150 mm	3 Ø10-150 mm
K2 Column	150	300	10 D13	2 Ø10-150 mm	2 Ø10-150 mm

Table 6. Beam dimension and configuration for Design B

Name	Dimension (mm)		Area	Bending reinforcement		Shear reinforcement	Torsion reinforcement
	Width	Depth		Top	Bottom		
B1 Beam	200	400	Support	4 D13	4 D13	Ø10-150 mm	2 Ø10
			Midspan	4 D13	4 D13	Ø10-150 mm	2 Ø10
B2 Beam	150	350	Support	3 D13	3 D13	Ø10-75 mm	-
			Midspan	3 D13	3 D13	Ø10-150 mm	-
B3 Beam	150	400	Support	3 D13	3 D13	Ø10-150 mm	2 Ø10
			Midspan	3 D13	3 D13	Ø10-150 mm	2 Ø10

Table 7. Column dimension and configuration for Design B

Name	Dimension (mm)		Bending reinforcement	Shear reinforcement	
	X axis	Y axis		X axis	And axis
K1 Column	200	300	10 D16	2 Ø10-150 mm	3 Ø10-150 mm
K2 Column	200	250	8 D16	2 Ø10-150 mm	2 Ø10-150 mm

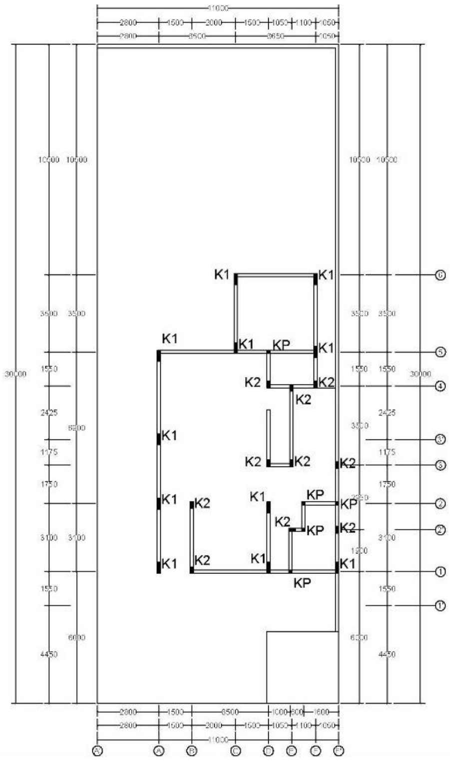

Figure 4. Colum layout for the first floor of Design A

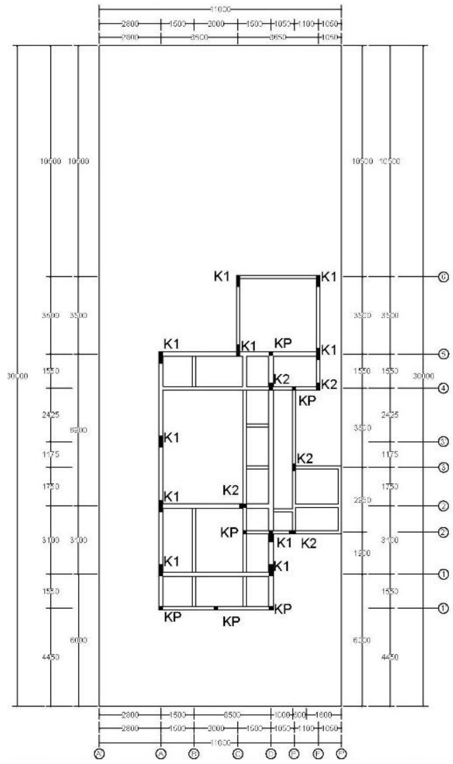

Figure 5. Colum layout for the second floor of Design A

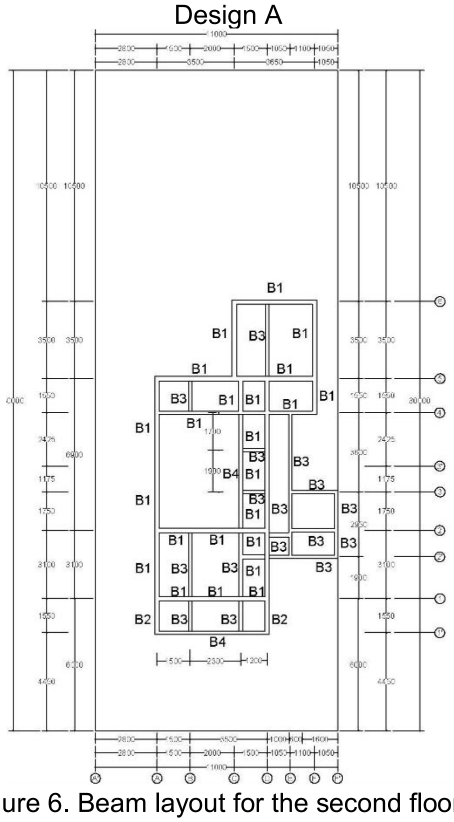

Figure 6. Beam layout for the second floor of Design A

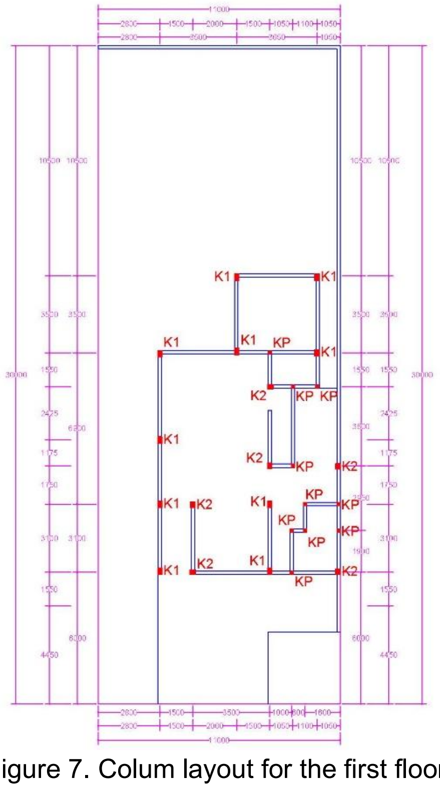

Figure 7. Colum layout for the first floor of Design B

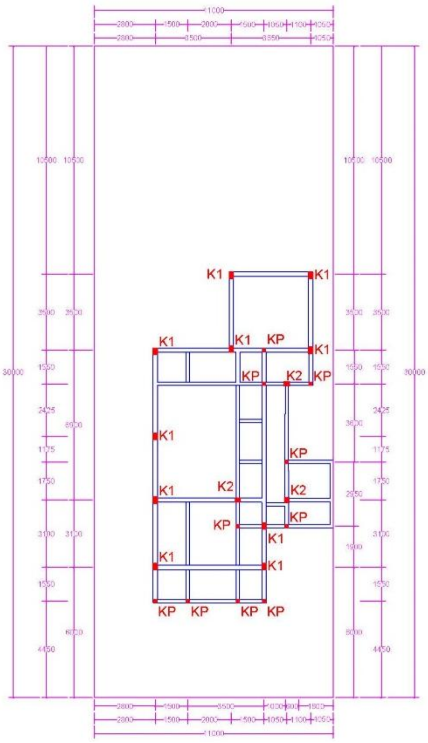

Figure 8. Colum layout for the second floor of Design B

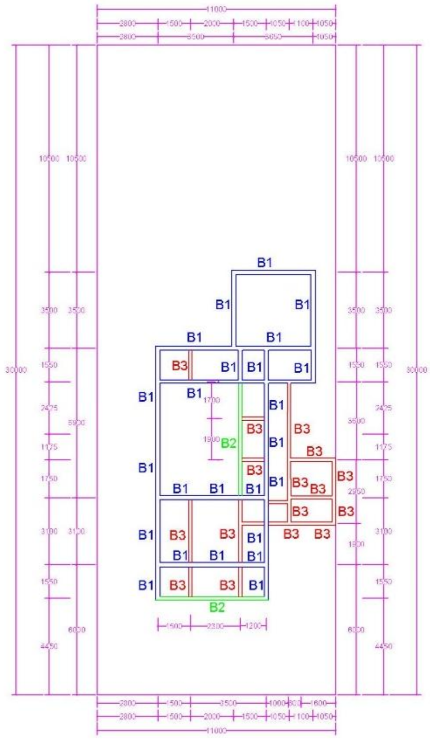

Figure 9. Beam layout for the second floor of Design B

Based on these data, a summary of concrete volume, reinforcement weight, and formwork area per meter length is presented in Table 8. To compare the total requirements of each design, the total length of each structural component was calculated based on the plan drawings. This total length was multiplied by the material requirements per meter to obtain the overall requirements for concrete volume, reinforcement weight, and formwork area (Table 9).

There is a difference in the total length of columns and beams between Design A and Design B. This difference arises from the variation in column cross-sectional dimensions. Design B uses more compact column sections, which provide higher structural capacity, resulting in shorter required member lengths compared to Design A. Further explanation is provided in the Discussion section.

Table 8. Material requirements of each structural component per unit meter

Name	Concrete volume, m^3	Steel bar weight, kg	Area of formwork, m^2
A Design			
B1 Beam	0.08	13.69	1.00
B2 Beam	0.08	16.07	1.00
B3 beam	0.0525	10.41	0.85
B4 beam	0.06	12.01	0.95
K1 Column	0.075	16.42	1.3
K2 Column	0.045	14.34	0.9

B Design			
B1 Beam	0.08	15.23	1.00
B2 Beam	0.0525	13.04	0.85
B3 beam	0.06	12.61	0.95
K1 Column	0.06	21.75	1
K2 Column	0.05	17.14	0.9

Table 9. The total length of each structural component and the total material requirements

Name	Total length, m	Concrete volume, m^3	Steel bar weight, kg	Area of formwork, m^2
A Design				
B1 Beam	59.6	4.77	815.92	59.60
B2 Beam	3.1	0.25	49.82	3.10
B3 beam	35.9	1.88	373.72	30.52
B4 beam	10.35	0.62	124.30	9.83
K1 Column	63	4.73	1034.46	81.90
K2 Column	45	2.03	645.30	40.50
Total		14.27	3043.52	225.45
B Design				
B1 Beam	60.95	4.88	928.27	60.95
B2 Beam	32.55	1.71	424.45	27.67
B3 beam	10.35	0.62	130.51	9.83
K1 Column	60	3.6	1305	60
K2 Column	27	1.35	462.78	24.3
Total		12.16	3251.01	182.75

Discussion

The total concrete volume and formwork area in Design B are 17.35% and 23.37% lower, respectively, than in Design A. However, the total reinforcement requirement is 6.38% higher than in Design A. Significant differences were found in the concrete volume and formwork area of the columns. This difference is due to the inefficiency of rectangular columns with high aspect ratios, which require more concrete volume compared to square columns. This finding is consistent with other studies showing that rectangular columns, especially those with large one-sided or two-sided ratios, have lower strength than square or circular columns (Krisnamurti et al., 2013; Yuniva et al., 2022; Shewale et al., 2024).

In structural design, one of the important factors affecting strength is the moment of inertia. The magnitudes of the X- and Y-axis moments of inertia in a rectangular column differ significantly due to the disparity in side lengths. In Design B, the column dimensions are more balanced in both axes, so the moments of inertia and capacities in the X and Y directions are relatively similar. In Design A, however, the axis with a width of 150 mm governs the capacity as the weak axis. This condition forces the other axis to increase in length in order to meet the load demand. In the calculation of the moment of inertia, the short side (150 mm) has a cubic influence, while the long side contributes linearly. Therefore, a large increase in the long side is required to compensate, making the column inefficient.

Table 10 presents the comparison between column demand and capacity for Design A and Design B. The results indicate that the nominal-to-ultimate moment ratios of the columns are comparable for both designs, with no pronounced differences observed. This suggests that Design B achieves a similar level of column strength performance to Design A, despite requiring a smaller concrete volume.

Table 10. Demand versus capacity of column

Name	Condition	$\phi M_n/M_u$
	A Design	
K1 Column	Axial force maximum	12.579
	Axial force minimum	27.528
	Moment X maximum	2.993
	Moment X minimum	3.992
	Moment Y maximum	1.306
	Moment Y minimum	1.008
K2 Column	Axial force maximum	8.167
	Axial force minimum	3.118
	Moment X maximum	1.562
	Moment X minimum	2.206
	Moment Y maximum	1.015
	Moment Y minimum	1.599
	B Design	
K1 Column	Axial force maximum	2.099
	Axial force minimum	28.161
	Moment X maximum	1.416
	Moment X minimum	1.210
	Moment Y maximum	1.257
	Moment Y minimum	1.053
K2 Column	Axial force maximum	12.07
	Axial force minimum	1.3
	Moment X maximum	3.606
	Moment X minimum	3.152
	Moment Y maximum	1.036
	Moment Y minimum	1.07

The material requirements directly affect production costs. Therefore, comparing the costs of the two designs is important. Based on the Regulation of the Minister of Public Works and Public Housing No. 28/PRT/M/2016 concerning Unit Price Analysis in the Public Works Sector, the material and labor costs for each work item were obtained (Table 11). These unit prices were multiplied by the total material quantities (Table 9) and then summed to determine the total cost of each design (Table 11). The results show that Design B has a 15.42% lower production cost compared to Design A.

Table 11. The price of the work and the total price of each design

Work	Unit	Sum	Unit price (IDR)	Total price (IDR)
		A Design		
Concrete volume	m^3	14.27	1,088,220.00	15,528,899.40

Steel bar weight	Kg	3043.52	16,685.69	50,783,231.23
Area of formwork	m^2	225.45	796,540.00	179,579,943.00
Total Price				245,892,073.63
B Design				
Concrete volume	m^3	12.04	1,088,220.00	13,232,755.20
Steel bar weight	Kg	3195.69	16,685.69	54,245,345.05
Area of formwork	m^2	181.55	796,540.00	145,567,685.00
Total Price				213,045,785.25

Conclusion

The shape of the column cross-section significantly affects structural capacity and material efficiency. Columns with a square cross-section (ratio close to 1) require 17.35% less concrete volume and 23.37% less formwork area compared to rectangular columns, although reinforcement requirements are 6.38% higher. Overall, the square column design resulted in a 15.42% reduction in construction costs. This reduction in concrete volume also implies lower cement consumption, which directly contributes to reducing CO_2 emissions. Based on the concrete volume, Design B used 856.32 kg (18.52%) less cement than Design A. The results support the principles of the Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Therefore, structural planning should not only focus on cost efficiency but also consider sustainability by minimizing material use and environmental impacts.

References

Akinyemi, A. P., Adekunle, A. O., Joseph, O. O., Anthony, A. I., & Dabara, D. I. (2017). The need for green building rating systems development for Nigeria: the process, progress, and prospect. International Journal of Art and Science, 7(2), 35-44.

Fayomi, G. U., Mini, S. E., Fayomi, O. S., & Ayoola, A. A. (2019). Perspectives on environmental CO2 emission and energy factor in Cement Industry. IOP Conference Series: Earth and Environmental Science, Vol. 331. Nigeria. https://doi.org/10.1088/1755-1315/331/1/012035

Jackson, D. J. (2020). Addressing the challenges of reducing greenhouse gas emissions in the construction industry: a multi-perspective approach [Doctoral Dissertation]. Scotland: University of Edinburgh, Business School. http://dx.doi.org/10.7488/era/269

Krisnamurti, K., Wiswamitra, K. A., & Kriswardhana, W. (2013). Pengaruh Variasi Bentuk Penampang Kolom Terhadap Perilaku Elemen Struktur Akibat Beban Gempa. Rekayasa Sipil, 7(1), 13–27.

Mei, L., & Wang, Q. (2021). Structural Optimization in Civil Engineering: A Literature Review. Buildings, 11(2), 66. https://doi.org/10.3390/buildings11020066

Negrin, I. A., Roose, D., Chagoyén, E. L., & Lombaert, G. (2021). Biogeography-Based Optimization of reinforced concrete structures including static soil-structure interaction. arXiv preprint arXiv:2103.05129, 1-15. https://doi.org/10.48550/arXiv.2103.05129

Our World in Data. (2025). Global Change Data Lab. Retrieved July 8, 2025, from https://ourworldindata.org/data-insights/global-cement-production-has-plateaued-over-the-last-decade

Rady, M., Mahfouz, S. Y., & Taher, S. E.-D. (2022). Optimal Design of Reinforced Concrete Materials in Construction. Materials, 15(7), 2625. https://doi.org/10.3390/ma15072625

Rahmanto, F., Elvira, & Supriyadi, A. (2023). Calculation of the Institut Teknologi dan Bisnis Sabda Setia Kota Pontianak Building's Structure. Jurnal Teknik Sipil, 23(1), 1-14. https://doi.org/10.26418/jtst.v23i1.60406

Serag-Eldin, G. M. (2010). A Conflict Management Model for Architectural Design Collaboration [Doctoral Dissertation]. Berkeley: University of California.

Shewale, M., Bahrami, A., Murthi, P., & Chidambaram, R. S. (2024). Enhancing Load-Carrying Capacity of Reinforced Concrete Columns with High Aspect Ratio Using Textile-Reinforced Mortar Systems. Buildings, 14(7), 2050. https://doi.org/10.3390/buildings14072050

Soomro, M., Tam, V. W., & Evangelista, A. C. (2023). Production of cement and its environmental impact. In Recycled Concrete: Technologies and Performance (pp. 11-46). Sawston: Woodhead Publishing.

Author et al. (2021). Peningkatan Kuat Tekan Pada Beton Geopolimer Akibat Metode Perawatan Dipanaskan. JMTS: Jurnal Mitra Teknik Sipil, 7(1), 79-86. https://doi.org/10.24912/jmts.v7i1.25150

Yuniva, T., Sulistyorini, D., & Shulhan, M. A. (2022). Perbandingan Kapasitas Kolom Dengan Variasi Bentuk Penampang (Studi Kasus Struktur Kolom Rumah Susun di Yogyakarta). Bangun Rekaprima, 8(1), 102-109.

Zhang, X., & Zhang, X. (2023). Design of low-carbon and cost-efficient concrete frame buildings: a hybrid optimization approach based on harmony search. Journal of

Asian Architecture and Building Engineering, 22(4), 2161-2174. http://dx.doi.org/10.1080/13467581.2022.2145202