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Performance Evaluation of Indonesian Prefabricated Modular School Building

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Abstract Indonesia, in the Pacific Ring of Fire and at the convergence of three tectonic plates, is vulnerable to natural disasters. Disasters cause property damage and disruptions. Therefore, accelerating post-disaster reconstruction is essential to speed recovery and normalize community life. The Indonesian government has developed modular prefabricated concrete technologies—Simple and Healthy Instant House (Rumah Instan Sederhana Sehat/RISHA), Excellent Home Instant Panel System (Rumah Unggul Sistem Panel Instan/RUSPIN), and Interlocking Frame Building Concrete Construction (Bangunan Rangka Interlok Konstruksi Beton/BRIKON)—to rebuild detached housing for disaster victims since 2015. RISHA is the most popular technology and has many certified applicators, so it has also been used to speed up public infrastructure reconstruction, including school reconstruction. This study will evaluate these three technologies, which have design limitations for school buildings, using assessment parameters developed for this research to achieve optimal results. To establish these assessment parameters, literature reviews, site observations, and structured interviews focused on design, production, and construction, weighting these parameters with the Analytical Hierarchy Process (AHP). Technique for Order Preference by Similarity to Ideal Solution Analysis (TOPSIS) was used to choose the best technology. For modular prefabricated schools, RUSPIN outperformed RISHA and BRIKON in design, production, and construction.

Keywords RISHA, RUSPIN, BRIKON, Modular Structural Panels, AHP, TOPSIS, Modular Elementary Schools, Earthquake-Resistant Construction

1. Introduction

Indonesia is a nation particularly susceptible to natural disasters, especially earthquakes, due to its position within the Pacific Ring of Fire. Consequently, Indonesia regularly endures earthquakes that can inflict significant damage on diverse infrastructures, including educational facilities. The earthquakes have obliterated those structures, particularly elementary schools, thereby disrupting the educational process and jeopardizing student safety [1].

The enhancement of educational institutions in Indonesia is prioritized at the elementary level [2][3], as the current compulsory education program exclusively encompasses elementary education. Thus, the development and improvement of elementary school infrastructure have emerged as a paramount priority [4]. The Indonesian government has prioritized education, particularly in light of the 2021 World Population Review data indicating that Indonesia's education system ranks 54th out of 78 countries. In accordance with the President's directive, the construction of elementary school facilities prioritizes the expedited establishment of earthquake-resistant structures to guarantee safety and the uninterrupted provision of education in disaster-prone regions [5][6].

Previous studies have extensively explored modular construction, especially steel-based modular systems, emphasizing their flexibility, construction speed, and material efficiency. However, these studies primarily focus on contexts outside disaster-prone regions, with limited application to educational infrastructure in Indonesia. Steel-based modular systems, while effective in some areas, may not fully address the unique challenges posed by Indonesia's geographical and socio-economic context, where local materials like concrete are more accessible, cost-effective, and resilient against earthquakes.

The proposed solution in Indonesia involves the utilization of local prefabricated modular panel technologies for structural components [7][8], — Simple and Healthy Instant House (Rumah Instan Sederhana Sehat/RISHA) as illustrated in Figures 1-3, Excellent Home Instant Panel System (Rumah Unggul Sistem Panel Instan/RUSPIN), and Interlocking Frame Building Concrete Construction (Bangunan Rangka Interlok Konstruksi Beton/BRIKON) — which have been specifically engineered for rapid and resilient construction. Unlike previous research, which often overlooks the integration of modular systems into educational infrastructure, this study adapts these technologies to meet the spatial and functional requirements of elementary schools. Furthermore, by employing Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the study offers a novel, quantitative approach to systematically evaluating design, production, and construction performance.

Figure 1. Utilization of Beams and Columns with RISHA in the Construction of Budibakti Elementary School

Figure 2. Construction Phase of Budibakti Elementary School Utilizing RISHA

Figure 3. Exterior Photograph of Budibakti Elementary School Constructed with RISHA

This research not only addresses the structural performance of prefabricated technologies but also evaluates their cost efficiency, construction speed, and waste management, providing a holistic assessment. By aligning these findings with Indonesia's national standards for classroom dimensions, the study bridges the gap between prefabricated modular technologies and the critical need for earthquake-resistant educational infrastructure in disaster-prone areas.

2. Objectives

This study will evaluate these three technologies, which have design limitations for school buildings, using assessment parameters developed for this research to achieve optimal results, weighting these parameters with the Analytical Hierarchy Process (AHP). Technique For Order Preference by Similarity to Ideal Solution Analysis (TOPSIS) was used to choose the best technology.

3. Methods

This study employed informants from prefabricated modular panel applicators and the Directorate of the Ministry of Public Works and Housing in Indonesia. The Ministry of Public Works and Housing, via the Directorate of Housing and Settlement Technical Guidance, designated applicators as the entities accountable for the production and construction phases of RISHA, RUSPIN, and BRIKON. These applicators are certified individuals in RISHA, RUSPIN, and BRIKON technologies, officially acknowledged through cooperative agreements with the Ministry. This initiative seeks to foster economic development via the Micro, Small, and Medium Enterprises (MSMEs) program. At the outset, Indonesia had 53 authorized RISHA applicators, 13 sanctioned RUSPIN applicators, and 2 certified BRIKON applicators. Nevertheless, many applicators became inactive over time. Those who continued to engage consolidated into enterprises, establishing a collective referred to as the Indonesian Panel System Technology Applicators (Aplikator Teknologi Sistem Panel Indonesia/ARTELINDO). The applicators participating in this research are PT Aksa Gaganan Nusantara (AGN), CV Kembang Bogor (KB), CV Rumah Panel Bangun Mandiri (RBM), and PT Bantala Cakra Sakti (BCS). All divisions of the Directorate of the Ministry of Public Works and Housing participating in this research contributed to the development and management of RISHA, RUSPIN, and BRIKON panels, namely: the structural design division, the architectural design division, and the applicator production and construction assistance division. To provide a clearer understanding of the research methodology, a concept map is presented in Figure 4.

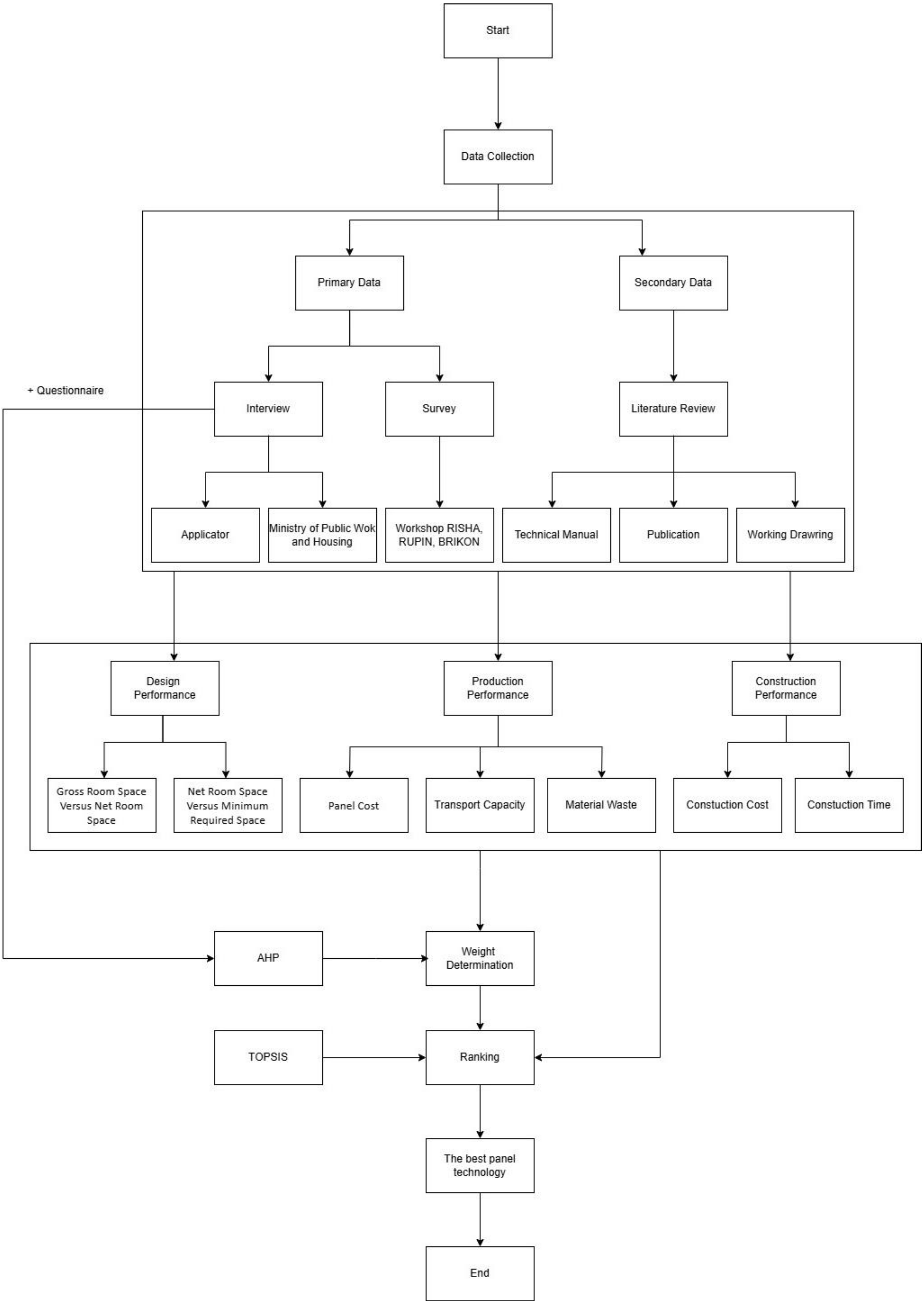


Figure 4. Concept Map

The initial phase entails gathering data regarding the design, production, and construction of modular prefabricated elementary school structures. This procedure is segmented into three comprehensive sub-stages. The initial sub-stage assesses the architectural design efficacy of RISHA, RUSPIN, and BRIKON technologies by determining the variance between gross and net spatial areas and juxtaposing the net space against the minimum classroom space standards specified in the Technical Guidelines for Standardized Design SE DJCK PUPR No. 47 of 2020. The data utilized are derived from measurements of each grid established in the RISHA-RUSPIN-BRIKON technical manual and working drawings, with the analysis aimed at assessing the architectural performance.

The second sub-stage evaluates the production efficiency of RISHA, RUSPIN, and BRIKON by determining panel costs, waste materials, and panel transport capacity for each grid. Panel cost information is obtained via interviews with applicators, electronic catalogs, and marketplaces. Information regarding waste materials is obtained through interviews with applicators and surveys conducted at manufacturing sites, whereas transport capacity is determined according to panel specifications. Mathematical analysis is performed to evaluate the production efficiency of each panel technology. The third sub-stage analyzes the construction efficacy of RISHA, RUSPIN, and BRIKON by gathering data via interviews with applicators, surveys of manufacturing facilities, and observations of active construction projects.

The second stage entails establishing the weights of the comprehensive design, production, and construction criteria through the Analytical Hierarchy Process (AHP) method. This involves establishing a hierarchical framework for questionnaire development, formulating pairwise comparison matrices for criteria and sub-criteria, and gathering responses from applicators and representatives of the the Ministry of Public Works and Housing through on-site visits to manufacturing facilities or virtual meetings via Zoom. The questionnaire data are analyzed with Super Decision software, and the results from each respondent are averaged using the geometric mean method to determine the weights of the criteria and sub-criteria. This phase determines the most significant criteria and sub-criteria for selecting the optimal local prefabrication technology for each type of panel.

The third stage establishes the ranking of the most effective technology—RISHA, RUSPIN, or BRIKON—for application in modular prefabricated elementary school structures utilizing the TOPSIS method. The AHP weights derived from the prior stage are integrated with the performance data from the initial stage and quantitatively analyzed using TOPSIS to determine the optimal technology for constructing modular prefabricated elementary school buildings. The study concludes with a recommendation for the most appropriate technology, derived from an extensive assessment of design, production, and construction efficacy.

4. Results

4.1. RISHA

RISHA is a prefabricated modular structural panel technology created by the Ministry of Public Works and Housing in 2004. RISHA was originally developed for earthquake-resistant structures with a total area of 36 m^2. To date, RISHA has been utilized for residential structures up to two stories, as illustrated in Figure 5, as well as for schools [9][10] and other facilities [11]. RISHA comprises three primary panel types, as illustrated in Figure 6: P1, P2, and P3.

Figure 5. Two-story RISHA house

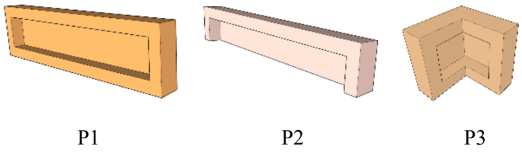
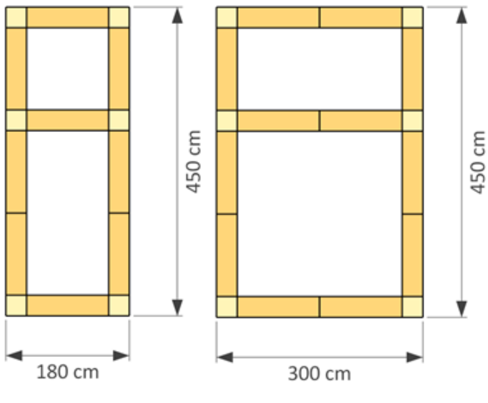


Figure 6. RISHA Panels

The P1 panel measures 120 cm in length, 30 cm in width, and 10 cm in thickness, serving as both a column and a beam [12][13]. The P2 panel, measuring 120 cm in length, 20 cm in width, and 10 cm in thickness, serves as a column stabilizer, whereas the P3 panel, with dimensions of 30 cm in length, 30 cm in width, and 10 cm in thickness, functions as a corner panel for column and beam junctions. RISHA employs connections utilizing bolts and nuts [14], and the material consists of reinforced concrete with a compressive strength of 25 MPa [15]. The dimensions of the RISHA small module are 180 cm, whereas the large module measures 300 cm [16], as illustrated in Figure 7.



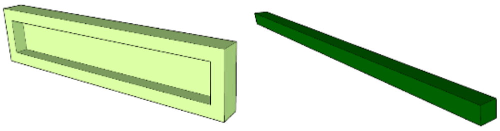
Small Module Large Module

Figure 7. RISHA Modules

4.2. RUSPIN

RUSPIN is a modular prefabricated structural technology created by the Ministry of Public Works and Public Housing in 2013. RUSPIN is utilized for earthquake-resistant modular housing [17][18], as illustrated in Figure 8, providing expedited construction and adaptability in module modifications [19]. RUSPIN offers two panel types, K1 and K2, as detailed in Figure 9.

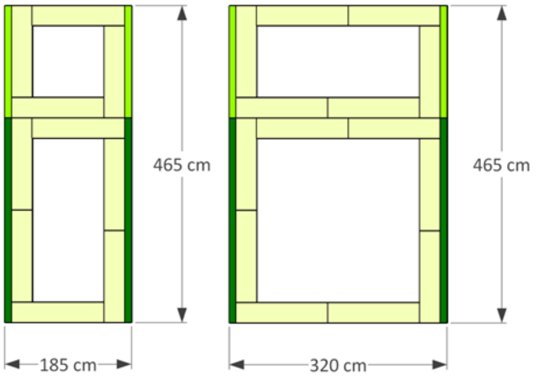
Figure 8. RUSPIN house



K1 K2

Figure 9. RUSPIN Panels

The K1 panel measures 135 cm in length, 30 cm in width, and 10 cm in thickness, serving as columns and beams. Simultaneously, the K2 panel, measuring 150 cm in length, 10 cm in width, and 10 cm in thickness, serves as a corner column [19]. RUSPIN employs utilizing bolts and nuts and reinforced concrete with a compressive strength of 25 MPa. The dimensions of the RUSPIN modules are 185 cm for the small size and 320 cm for the large size, as indicated in Figure 10.



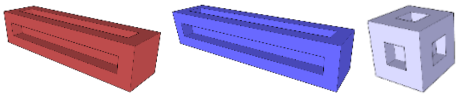
Small Module Large Module

Figure 10. RUSPIN Modules

4.3. BRIKON

BRIKON is a modular prefabricated structural technology created by the Ministry of Public Works and Public Housing in 2020. BRIKON is utilized for the construction of earthquake-resistant modular housing up to two stories, as illustrated in Figure 11. This technology employs steel corner panels to improve stability in two-storey buildings. BRIKON comprises four panel types: P80, P100, P120, and S. In the construction of BRIKON elementary school buildings, three panel types are utilized: P80, P100, P120, and S, as indicated in Figure 12.

Figure 11. BRIKON house

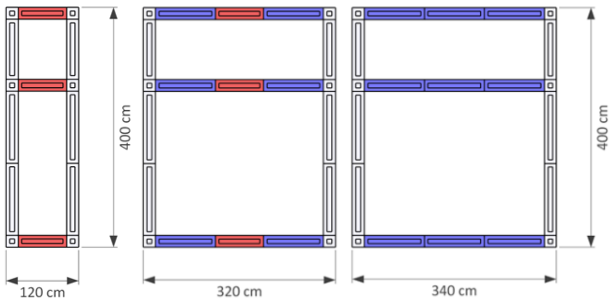


P80 P100 S

Figure 12. BRIKON Panels

The P80 panel measures 80 cm in length, 20 cm in width, and 20 cm in thickness, whereas the P100 panel measures 100 cm in length, 20 cm in width, and 20 cm in thickness. P120 panel measures 120 cm in length, 20 cm in width, and 20 cm in thickness The S panel, measuring

20 cm in length, 20 cm in width, and 20 cm in thickness, functions as a corner panel for the connection of columns and beams [20]. BRIKON utilizes turnbuckle joints, offering enhanced installation flexibility, and incorporates reinforced concrete with a strength of 25 MPa. BRIKON provides various small module dimensions, specifically 120 cm, 140 cm, and 160 cm in addition to larger modules measuring 260 cm, 280 cm, 300 cm, 320 cm, and 340 cm. In the construction of BRIKON elementary school buildings, only two large modules will be employed: 320 cm and 340 cm, as indicated in Figure 13.



Small Module Large Module

Figure 13. BRIKON Modules

4.4. Comparison between RISHA, RUSPIN, and BRIKON

Table 1 facilitates a comparison among the three prefabricated modular structural panel technologies: RISHA, RUSPIN, and BRIKON, highlighting substantial disparities in dimensions, functions, assembly, connections, materials, and the formation of both small and large modules. RISHA comprises three panel types: P1, P2, and P3. RUSPIN employs two varieties of panels, K1 and K2. BRIKON utilizes four panel types: P80, P100, P120, and S.

The three prefabricated modular technologies—RISHA, RUSPIN, and BRIKON—demonstrate distinct differences in terms of design, construction, and efficiency. RISHA employs three primary panel types: P1 (columns and beams), P2 (column stabilizers), and P3 (corner panels). These panels are used to create small (180 cm) and large (300 cm) modules with a thickness of 10 cm. However, the use of L-shaped corner panels (P3) results in reduced effective space within the modules, making the design less spatially efficient. RUSPIN, on the other hand, offers two panel types: K1 (columns and beams) and K2 (corner columns), with the same thickness of 10 cm. Its interlocking design allows for more flexible configurations and improved spatial efficiency, with module sizes ranging from 185 cm to 320 cm. In contrast, BRIKON utilizes four types of panels: P80, P100, P120, and S (corner panels). BRIKON panels are thicker (20 cm) and come in a wider range of sizes, from 120 cm to 340 cm, providing greater design flexibility.

In terms of construction, RISHA relies on bolt-and-nut connections. Its lightweight panels (less than 50 kg) facilitate manual handling and transportation without heavy machinery. However, the lack of interlocking mechanisms requires additional measures to ensure structural stability during assembly. RUSPIN also employs bolt-and-nut connections but incorporates an interlocking system that enhances stability and accelerates the construction process. BRIKON, in contrast, uses turnbuckle connections, which offer greater flexibility and structural stability, especially for two-story buildings, although the system is more complex and time-consuming to assemble.

Efficiency varies significantly among the three technologies. RISHA stands out for its lower panel costs, making it an economically attractive option. However, the design results in higher material waste compared to RUSPIN and BRIKON. RUSPIN excels in construction speed and spatial efficiency, generating less waste and providing greater structural stability. BRIKON, while more expensive, produces minimal material waste and offers the highest design flexibility due to its variety of panel dimensions. However, its longer construction time may limit its applicability in urgent post-disaster scenarios.

In summary, RUSPIN emerges as the most versatile technology, balancing design flexibility, construction efficiency, and spatial optimization. RISHA is cost-effective but less efficient in terms of space utilization and waste management. BRIKON provides superior modular flexibility and stability, particularly for multi-story structures, albeit at a higher cost and with longer assembly times.

Both RISHA and BRIKON utilize corner panels for the assembly of structural components. RISHA and RUSPIN utilize nuts and bolts for connections, whereas BRIKON employs turnbuckles. Concurrently, RUSPIN employs an interlocking mechanism for the assembly of its structural components and utilizes nuts and bolts for connections. All three technologies utilize reinforced concrete with a uniform strength of 25 MPa, ensuring comparable durability for structural loads. RISHA can produce small modules measuring 180 cm in length and large modules measuring up to 300 cm. RUSPIN possesses a marginally greater capacity, featuring small modules of 185 cm and large modules extending up to 320 cm, which exceed the dimensions of those offered by RISHA. BRIKON, conversely, provides a broader array of module sizes, encompassing small modules of 120 cm and 140 cm, as well as large modules spanning from 260 cm to 340 cm, thereby enhancing flexibility in structural design. RUSPIN possesses longer panel dimensions and larger modules than RISHA, whereas BRIKON offers a wider range of module size variations, thereby enhancing design flexibility. BRIKON employs turnbuckles for connections, contrasting with RISHA and RUSPIN's nut and bolt system, each method presenting distinct advantages and disadvantages based on the project's specific requirements.

Table 1. Comparison of Local Prefabricated Modular Technologies in Indonesia

Technology	Panel	Dimensions	Function	Configuration	Connection	Material	Small Module	Large Module
RISHA	P1	Length 120 cm, Width 30 cm, Thickness 10 cm	Column and beam	With corner panel	Bolt and nut	Reinforced concrete 25 MPa	180 cm	300 cm
	P2	Length 120 cm, Width 20 cm, Thickness 10 cm	Column balancer					
	P3	Length 30 cm, Width 30 cm, Thickness 10 cm	Corner panel, column and beam junction					
RUSPIN	K1	Length 135 cm, Width 30 cm, Thickness 10 cm	Column and beam	Interlock	Bolt and nut	Reinforced concrete 25 MPa	185 cm	320 cm
	K2	Length 150 cm, Width 10 cm, Thickness 10 cm	Corner column					
BRIKON	P80	Length 80 cm, Width 20 cm, Thickness 20 cm	Column and beam	With corner panel	Turnbuckle	Reinforced concrete 25 MPa	120 cm, 140 cm, 160 cm	260 cm, 280 cm, 300 cm, 320 cm, 340 cm
	P100	Length 100 cm, Width 20 cm, Thickness 20 cm	Column and beam					
	P120	Length 120 cm, Width 20 cm, Thickness 20 cm	Column and beam					
	S	Length 20 cm, Width 20 cm, Thickness 20 cm	Corner panel, column and beam junction					

Table 2. Elementary School Building's Grid Based on Its Technology

	RISHA	RUSPIN	BRIKON
Grid Dimensions	780 cm x 780 cm	825 cm x 825 cm	780 cm x 780 cm
Module Sequence	Large Module – Small Module – Large Module	Large Module – Small Module – Large Module	Large Module – Small Module – Large Module
Module Dimensions	300 cm – 180 cm – 300 cm	320 cm – 185 cm – 320 cm	340 cm – 120 cm – 320 cm

4.5. Design of Elementary School Buildings Using RISHA, RUSPIN, and BRIKON

The construction of elementary school classrooms utilizing RISHA, RUSPIN, and BRIKON technologies involved arranging structural grids for both length and width to comply with the minimum classroom area standard of 56 m^2 for 28 students, as specified in the Technical Guidelines for Standardized Design SE DJCK PUPR No.47 of 2020. The school design employing RISHA technology was derived from a previously executed project in West Java, with modifications made in accordance with the Ministry of Education and Culture Regulation Number 24 of 2007 to conform to RISHA modular technology. The configuration of the elementary school classroom is illustrated in Table 2.

The schools constructed using RISHA technology possess standard dimensions of 780 cm by 780 cm, as indicated in Figure 14. The RISHA classroom grid comprises a sequence of large, small, and large modules, specifically measuring 300 cm, 180 cm, and 300 cm, respectively, to satisfy the requisite area standard. The structural thickness of RISHA is 30 centimeters on each side. The configuration and cross-sectional illustration of the classroom grid are depicted in Figures 15 and 16 supplied by the Ministry of Public Works and Public Housing.

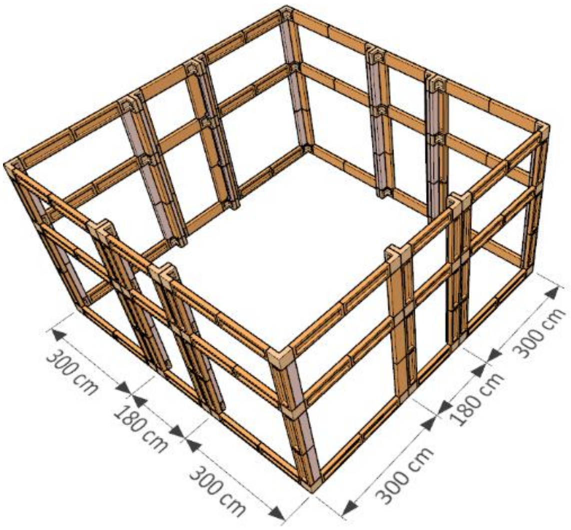


Figure 14. RISHA Classroom Grid

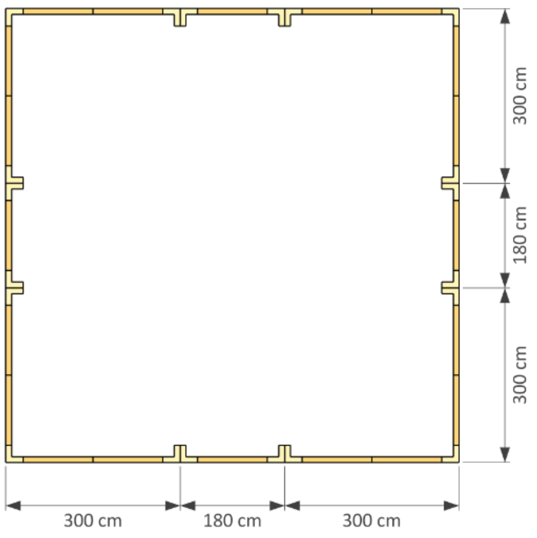


Figure 15. Floor Plan of RISHA Elementary School Classroom [21]

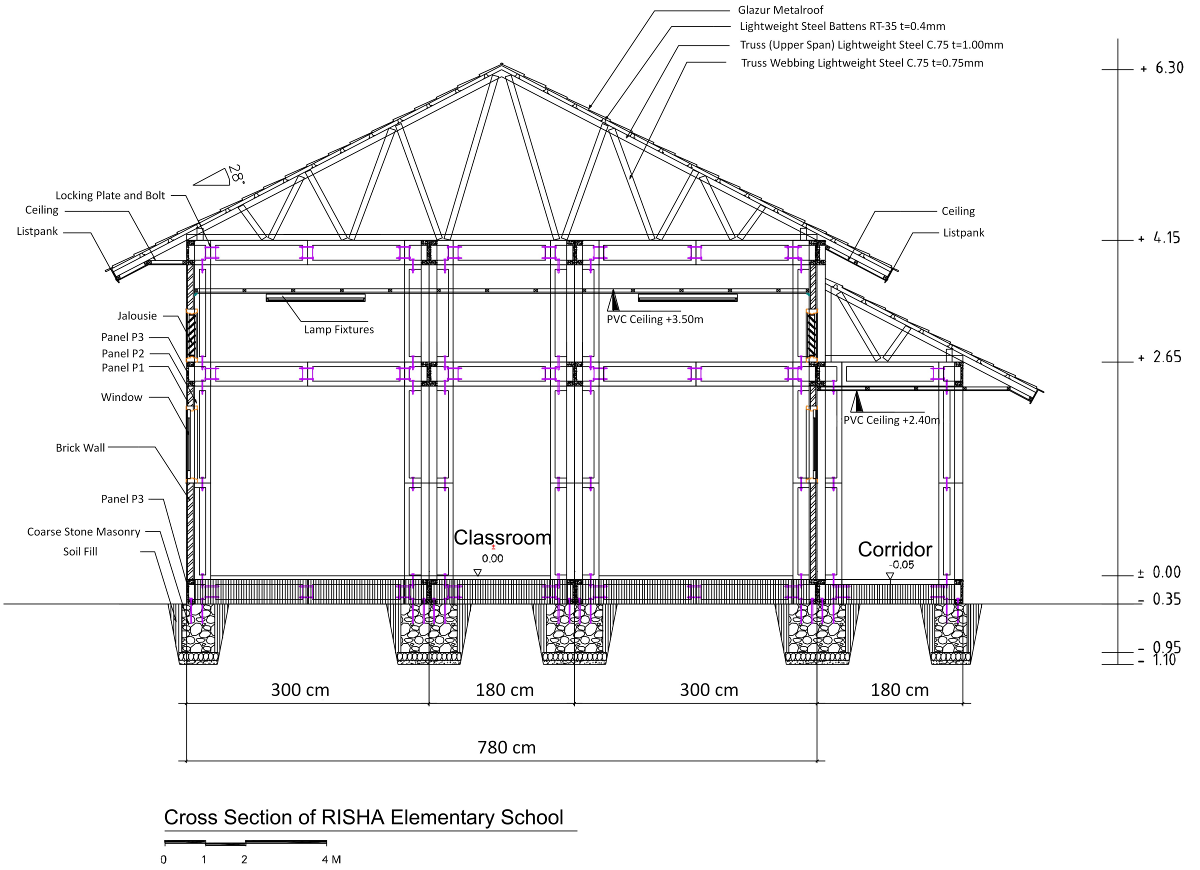


Figure 16. Cross-Section of RISHA Elementary School Classroom [21]

RUSPIN comprises the identical configuration as RISHA, featuring large, small, and large modules arranged in succession, specifically measuring 320 cm, 185 cm, and 320 cm, to create a classroom grid with overall dimensions of 825 cm x 825 cm, as indicated in Figure 17. The structural thickness of RUSPIN is 10 centimeters on each side. Each grid, in both dimensions, is engineered to conform to the standard spatial requirements of a classroom, consistent with the RISHA classroom grid. RUSPIN modules are engineered to offer enhanced flexibility and construction simplicity, featuring larger dimensions than RISHA, thereby facilitating more spacious classrooms. This expansive modular system provides benefits such as expedited assembly and the capacity to efficiently cover larger areas, thereby improving the functionality and comfort of classroom environments.

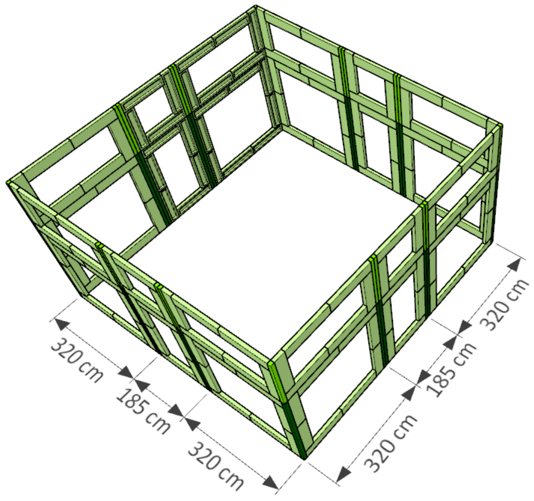


Figure 17. RUSPIN Classroom Grid

BRIKON employs a sequential arrangement of large, small, and large modules measuring 340 cm, 120 cm, and 320 cm, respectively, to create a classroom grid with overall dimensions of 780 cm x 780 cm, as indicated in Figure 18. The structural thickness of BRIKON is 20 centimeters on each side. Each grid, in both dimensions, is engineered to conform to standard classroom size specifications, consistent with the RISHA classroom grid. BRIKON modules utilize a turnbuckle connection system to unite the reinforced concrete panels, enhancing stability, particularly at the intersections of columns and beams [22]. The BRIKON classroom grid is engineered to provide diversity in structural design while adhering to dimensions comparable to the RISHA classroom grid, thereby ensuring conformity with mandated classroom space standards.

This study employed a sequential combination of large, small, and large modules, utilizing grid sizes comparable to those of RISHA primary schools, for classroom construction with RUSPIN and BRIKON technology. This led to classrooms with dimensions and configurations akin to RISHA technology. The classroom matrices of these three technologies facilitated an objective evaluation regarding design, production, and construction. The design performance of primary school buildings utilizing local prefabricated modular structural panels from RISHA, RUSPIN, and BRIKON technologies was assessed according to two sub-criteria: gross room space compared to net room space and net room space relative to the minimum required space as per Indonesian National Standards.

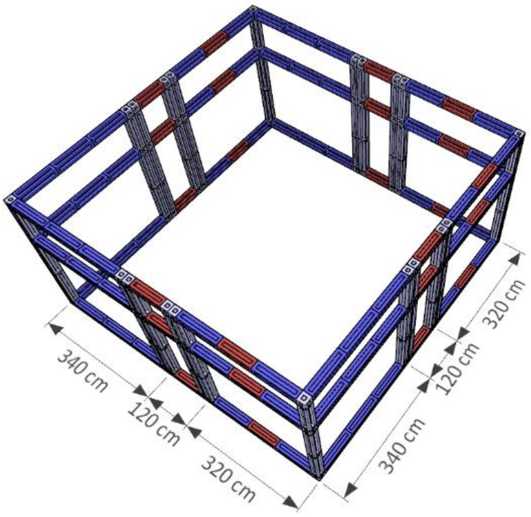


Figure 18. BRIKON Classroom Grid

4.6. Production and Construction of Elementary School Buildings Using RISHA, RUSPIN, and BRIKON

The sub-criteria influencing the production and construction phases of locally prefabricated modular structural panels in Indonesia were established through an analysis of the processes inherent to each stage of the production and construction cycle of RISHA, RUSPIN, and BRIKON technologies. Indonesia, possessing the fourth-largest population globally, has advanced technology that optimizes job creation and emphasizes human labor over machinery. As a developing nation, Indonesia promotes the establishment of businesses with minimal capital to enhance employment via Micro, Small, and Medium Enterprises (MSMEs) [23]. The manufacturing of locally prefabricated modular structural panels in Indonesia targets MSME-scale enterprises, with capital between USD 3,143.2 and USD 31,431.9 and revenue ranging from USD 18,859.1 to USD 157,159.3. This strategy sought to enhance the participation of MSMEs in the construction industry and foster increased employment, aligning with governmental policies to optimize the capabilities of small enterprises in local infrastructure advancement. Employing a labor-intensive methodology allows for the more efficient implementation of RISHA, RUSPIN, and BRIKON technologies within

Indonesia's economy, which favors human labor over machinery utilization [24].

RISHA, RUSPIN, and BRIKON are technologies developed by the Ministry of Public Works and Housing to assist MSMEs through a labor-intensive methodology. The panels have a maximum weight of 50 kg, enabling two workers to lift them, in compliance with manual handling regulations that stipulate a maximum lifting limit of 25 kg / worker. The panel length is restricted to 180 cm, facilitating transportation by motorcycle, particularly in disaster-stricken regions with limited road access. The design of these panels sought to diminish dependence on heavy machinery, facilitating implementation by small enterprises with constrained financial resources. This transportation flexibility is essential, especially in disaster-stricken regions where access for larger vehicles is frequently limited or compromised.

The production efficiency of elementary school structures utilizing local prefabricated modular structural panels—RISHA, RUSPIN, and BRIKON—was assessed according to three sub-criteria: panel cost [25][26], transportation capacity per light truck [27], and waste materials [28][29]. Table 3 displays the production data for each technology. The panel cost was determined according to the specifications for each classroom grid and the market price in 2024. The panel costs for RISHA were USD 9.7 for P1, USD 9 for P2, and USD 7.7 for P3. The panel costs for K1 and K2 for RUSPIN were USD 8.4 and USD 11.7, respectively. The panel costs for BRIKON were USD 6.9 for P80, USD 8.8 for P100, USD 10.1 for P120, and USD 3.2 for S. The transportation capacity of each light truck was determined by dividing the total volume of panels by the truck's capacity of 8.4 m^3. The waste materials from the production process were examined, revealing that the remaining reinforcement measured 7.3 cm for RISHA, 6 cm for RUSPIN, and 0 cm for BRIKON, signifying that BRIKON possesses the minimal quantity of waste material.

Table 3. Production Data of RISHA, RUSPIN, BRIKON

	RISHA	RUSPIN	BRIKON
Panel Price	P1 - USD 9.7	K1 - USD 8.4	P80 - USD 6.9
	P2 - USD 9	K2 - USD 11.7	P100 - USD 8.8
	P3 - USD 7.7		P120 - USD 10.1
			S - USD 3.2
Transport Capacity	Panel volume per classroom / a light truck volume		
Material Waste	7.3 cm/ panel	6 cm/ panel	0 cm/ panel

The construction performance was assessed according to two sub-criteria: cost [30] and time [31][32]. Table 4 displays the construction data for each technology. Construction costs were determined by multiplying the total number of panels by the average construction cost for each technology. The construction costs, according to market prices in 2024 as presented in Table 4, demonstrate that RUSPIN offers the most economical construction expenses. The construction duration was determined by multiplying the total number of panels by the time allocated for each panel (in minutes), subsequently dividing the result by 60 to convert it into hours. The construction was executed by four workers, each working eight hours daily. The construction duration for each panel, as indicated in Table 4 [22], demonstrates that RUSPIN exhibits the most rapid construction time.

Table 4. Construction Data of RISHA, RUSPIN, and BRIKON

	RISHA	RUSPIN	BRIKON
Construction Cost	USD 2.5/ panel	USD 2.3/ panel	USD 3.5/ panel
Construction Time	8.67 minutes/ panel	7 minutes/ panel	10 minutes/ panel

5. Discussion

5.1. Design, Production, and Construction Review of RISHA, RUSPIN, and BRIKON Elementary School Buildings

Table 5 displays Design, Production, and Construction Review of RISHA, RUSPIN, and BRIKON Elementary School Buildings. The RISHA elementary school buildings feature a classroom grid with overall dimensions of 780 cm x 780 cm. The structural thickness is 30 cm on each side, resulting in net grid dimensions of 720 cm x 720 cm. Classrooms were designed in a square configuration, ensuring that the length and width are equal. A total of 168 panels were utilized to construct one classroom grid, comprising 72 P1 panels, 48 P2 panels, and 48 P3 panels. The sequence of modules comprised a large module (300 cm), a small module (180 cm), and another large module (300 cm).

The design analysis indicated a gross room space of 9 m^2 compared to a net room space, with a deviation from the standard room area of -4.16 m^2. The production analysis revealed that the total cost of P1 panels was USD 696.6, P2 panels was USD 434.5, and P3 panels was USD 368, resulting in a cumulative panel cost of USD 1,499. The waste material generated measured 1,176 cm, and the transportation capacity with a light truck was 0.53 truckloads. The construction analysis indicated a duration of 10.11 hours and an expenditure of USD 419.5. The aggregate cost of the panels and construction totaled USD 1,918.6.

Table 5. Design, Production, and Construction Review of RISHA, RUSPIN, and BRIKON Elementary School Buildings

Criteria	Sub Criteria	Prefabricated Modular Panel Technology		
		RISHA Elementary Schools	RUSPIN Elementary Schools	BRIKON Elementary Schools
Design Performance	Gross Room Space Versus Net Room Space	9 m^2	3.26 m^2	6.08 m^2
	Net Room Space Versus Minimum Required Space Based on Indonesian National Standard	-4.16 m^2	8.8 m^2	-1.24 m^2
Production Performance	Panel Cost	USD 1,499	USD 1,552	USD 1,566.3
	Transport Capacity / Truck Load	0.53	0.46	0.85
	Material Waste	1,176 cm	913 cm	0 cm
Construction Performance	Construction Cost	USD 339.2	USD 339.2	USD 754.4
	Construction Time	10.11 hours	7.19 hours	18.46 hours

RUSPIN elementary school buildings feature a classroom grid with overall dimensions of 825 cm x 825 cm, incorporating a structural thickness of 10 cm on each side, yielding a net grid dimension of 805 cm x 805 cm. The classroom grid comprised 64 K1 panels and 84 K2 panels, totaling 148 panels. The sequence of modules comprised one large module (320 cm), one small module (185 cm), and an additional large module (320 cm).

The design analysis for RUSPIN elementary school buildings indicated a gross room space exceeding net room space by 3.26 m^2, with a deviation from the standard of 8.8 m^2. The production analysis indicated that the total cost of K1 panels was USD 537.1, and K2 panels was USD 1,014.9, culminating in an aggregate panel expense of USD 1,552. The waste material measured 913 cm, and the transport capacity of a light truck was 0.46 truckloads. The construction analysis revealed a duration of 7.19 hours and expenses amounting to USD 339.2. The total cost of the panel, inclusive of construction, amounted to USD 1,891.2.

The final BRIKON elementary school buildings feature a classroom grid with overall dimensions of 780 cm x 780 cm, incorporating a structural thickness of 20 cm on each side, yielding a net grid dimension of 740 cm x 740 cm. The classroom grid was constructed using 36 P80 panels, 36 P100 panels, 84 P120 panels, and 60 S panels, totaling 216 panels. The modules were organized sequentially, comprising a large module (340 cm), a small module (120 cm), and another large module (320 cm).

The design analysis indicated a gross room space of 6.08 m^2 compared to the net room space, with a deviation from the standard room area of -1.24 m^2. The production analysis indicated the total costs of panels as follows: P80 panels at USD 248.9, P100 panels at USD 316.8, P120 panels at USD 844.9, and S panels at USD 1,599.6, culminating in a total panel cost of USD 1,599.3. No material waste was produced (0 cm), and the load capacity utilizing a light truck was 0.85 truckloads. The construction analysis indicated a duration of 18.46 hours and expenses totaling USD 754.4. The aggregate expense for panels and construction amounted to USD 2,353.6.

5.2. Weight Determination for Comparison

The preliminary AHP questionnaire included inquiries designed to identify the highest-performing panel by evaluating the performance criteria of design, production, and construction. In the subsequent phase, the AHP questionnaire was formulated to evaluate optimal design performance by juxtaposing design sub-criteria: net room space versus the minimum required space, and gross room space versus net room space. The AHP questionnaire for production performance encompassed inquiries that compared production sub-criteria, including panel pricing, transportation capacity via a light truck, and waste materials from the production process. Simultaneously, the AHP questionnaire regarding construction performance included inquiries that compared construction sub-criteria, such as costs and time. All AHP results satisfied the inconsistency criterion of < 0.1, signifying that the comparisons among criteria were coherent. The questionnaire results were analyzed using Super Decision software. The weighting diagram is presented in Table 6.

The evaluation of design, production, and construction criteria by different practitioners of modular prefabricated panel technology revealed that each practitioner allocated distinct weights to each phase, based on their respective priorities and challenges. AGN and KB regarded all stages as equally significant, attributing a 33% weight to each, as they perceived all stages to be of equal importance. During the design phase, adherence to spatial area standards was prioritized over the distinction between gross and net room space. Conversely, in the production phase, transport capacity and panel cost became the predominant issues, owing to the difficulties associated with distributing modular panels in earthquake-impacted regions.

Table 6. Weighting by Respondents

Criteria	Sub Criteria	Weighting by Respondents (%)						
		AGN	KB	RBM	BCS	The Ministry of Public Works and Housing Structure	The Ministry of Public Works and Housing Design	The Ministry of Public Works and Housing Support
Criteria	Design Performance	33	33	23.12	13.97	20	45.45	32.75
	Production Performance	33	33	70.85	52.78	20	45.45	25.99
	Construction Performance	33	33	6.03	33.25	60	9.09	41.26
Sub Criteria Design Performance	Gross Room Space Versus Net Room Space	5.56	5.56	11.56	10.47	16.67	22.73	27.29
	Net Room Space Versus Minimum Required Space	27.78	27.78	11.56	3.49	3.33	22.73	5.45
Sub Criteria Production Performance	Panel Cost	12.22	15.78	35.39	13.63	6.67	11.74	18.43
	Transport Capacity / Truck Load	19.4	15.78	29.37	5.52	6.67	4.76	4.64
	Material Waste	1.7	1.75	6.09	33.62	6.67	28.94	2.93
Sub Criteria Construction Performance	Construction Cost	16.67	5.56	0.86	5.54	30.00	4.54	6.87
	Construction Time	16.67	27.78	5.17	27.71	30.00	4.54	34.38

In contrast to AGN and KB, RBM and BCS prioritized the production phase. RBM emphasized the significance of production quality, attributing it a weight of 70.85%, whereas BCS allocated a weight of 52.78% to production, deeming the quality of modular panels essential for the structural reliability of the building. Both considered panel price and transport capacity as critical sub-criteria during the production phase.

The Ministry of Public Works and Housing highlighted the construction and design phases within both the structural and architectural design divisions. The previous division regarded the construction criteria as paramount, attributing it a weight of 60%, whereas the subsequent division emphasized both design and production. This ministry regarded the sub-criteria of construction time and cost as equally significant to guarantee that projects were finalized punctually and within financial constraints. Each applicator and the Ministry of Public Works and Housing possess distinct priorities in evaluating the performance of modular prefabricated panels, which mirror the unique challenges encountered in production and on-site construction processes.

The respondents' weighting of criteria and sub-criteria indicated that the applicators AGN and KB employed a comparable methodology in their work. Both allocated equal importance to design, production, and construction performance, demonstrating a balanced emphasis on all phases of their projects, from planning to execution. Conversely, RBM emphasized production efficiency. Their primary focus on the production process, coupled with minimal involvement in the design phase, rendered the quality and efficiency of panel production their principal concern.

Conversely, the Ministry of Public Works and Housing Structure and Supervision prioritized construction performance, as its primary responsibilities encompassed the inspection and oversight of construction execution in the field. Consequently, construction emerged as the paramount criterion for ensuring that the edifices adhered to standards and could endure critical conditions, such as earthquakes. The Ministry of Public Works and Housing Design assigned diminished importance to construction performance, believing that the design had attained an optimal standard, and prioritized the implementation and optimization of design criteria during the production and construction phases. This disparity in priorities demonstrated how the roles and responsibilities of each party in the prefabricated modular project affected their evaluation of the different stages. Applicators prioritized production criteria, whereas those overseeing field operations emphasized construction criteria.

The outcomes from the seven respondents were averaged employing the geometric mean method, as shown in Table 7, resulting in the weight for each criterion and sub-criterion. The optimal panel performance comprised design performance at 30.58%, production performance at 41.98%, and construction performance at 27.43%. Interviews with respondents indicated that the production criterion was paramount, as the quality of each panel for the RISHA, RUSPIN, and

BRIKON technologies was established at this phase. The quality of the panel was essential as it constituted the principal structural element of the building. If these components fail to meet the requisite quality standards for the reliability of the proposed structure, the building would be susceptible to collapse [33].

The design performance consisted of two sub-criteria: net room space versus minimum required space based on Indonesian National Standard, with a weight of 14.05%, and gross room space versus net room space with a weight of 16.53%. Gross room space versus net room space was considered more important because this sub-criterion distinguished each technology. Although RISHA and RUSPIN have the same panel thickness, the different panel configurations resulted in variations in gross room space versus net room space. For instance, panel P3, which has an L-shaped design in RISHA, caused inefficient use of space. The calculation of the structural thickness difference was conducted on all four sides, meaning that the larger the difference, the smaller the resulting space, indicating less efficient design.

Production performance consisted of three sub-criteria: panel price with a weight of 19.13%, transport capacity with a weight of 13.51%, and waste materials from the production process with a weight of 9.32%. According to interviews with the respondents, panel price was considered the most important sub-criterion because a lower price was more attractive to the private market compared to conventional technology [34]. Transport capacity was deemed less important, as issues rarely arose except when infrastructure was damaged during delivery. Waste materials had the lowest weight since waste, whether steel waste could be resold by weight [35], making this sub-criterion less of a concern.

Construction performance consisted of two sub-criteria: construction cost with a weight of 7.68% and construction time with a weight of 19.75%. Construction time was considered more important than construction cost because RISHA, RUSPIN, and BRIKON panels were often used by the government for post-disaster relocation projects [36]. In such situations, affected residents need to regain housing as quickly as possible. These prefabricated modular panel technologies were often praised for their rapid construction speed, even outperforming temporary shelters in disaster-stricken areas. Therefore, time efficiency became a crucial sub-criterion in construction performance. Construction criteria had the smallest overall weight because prefabricated modular technologies were designed to minimize on-site work. The panels were easy and quick to install, and thus, human error during the construction phase was believed to be minimal. With modular technology, panel installation became more efficient, reducing the risk of mistakes during on-site construction.

5.3. Ranking

The optimal panel was selected utilizing the TOPSIS methodology. Table 8 displays the outcomes of the TOPSIS analysis, informed by the criterion weights obtained through the AHP method. Seven criteria were employed to assess the performance of different prefabricated modular panels: gross room space versus net room space, net room space versus minimum required space, panel cost, material waste, load capacity, construction cost, and construction time. Each criterion was assigned a weight based on its significance, with construction time receiving the highest weight (19.75%), signifying its status as the most critical factor in the evaluation. Simultaneously, construction costs constituted the least significant proportion at 7.68%.

The assessment of three local prefabricated modular panel technologies in Indonesia—RISHA, RUSPIN, and BRIKON is conducted. Regarding gross room space versus net room space, RUSPIN exhibited the lowest value (3.26), signifying superior structural efficiency relative to RISHA (9) and BRIKON (6.08). The disparity in room size from the minimum standard indicated that RUSPIN exhibited the highest value (8.80), signifying superior compliance with the required dimensions, whereas RISHA (-4.16) and BRIKON (-1.24) demonstrated a deficiency in space.

Table 7. Average Weighting with Geomean

Criteria	Sub Criteria	Geomean (%)
Criteria	Design Performance	30.58
	Production Performance	41.98
	Construction Performance	27.43
Sub Criteria Design Performance	Gross Room Space Versus Net Room Space	16.53
	Net Room Space Versus Minimum Required Space	14.05
Sub Criteria Production Performance	Panel Cost	19.13
	Transport Capacity / Truck Load	13.51
	Material Waste	9.32
Sub Criteria Construction Performance	Construction Cost	7.68
	Construction Time	19.75

Table 8. Ranking of the Best Panel Technology using the TOPSIS Method

	Gross Room Space Versus Net Room Space	Net Room Space Versus Minimum Standard	Panel Cost	Material Waste	Transport Capacity / Truck Load	Construction Time	Construction Cost
Weights (from AHP)	14.05	16.53	19.13	9.32	13.51	19.75	7.68
Description	cost	benefit	cost	cost	cost	cost	cost
RISHA	9	-4.16	USD 1,499	7.00	0.53	10.11	USD 419,51
RUSPIN	3.26	8.80	USD 1,552	6.17	0.46	7.19	USD 339,2
BRIKON	6.08	-1.24	USD 1,599.2	0.00	0.85	18.46	USD 754,4
Divisors	11.33993	9.81240	42724391.248	9.33107	1.10227	22.24140	14752911.1395
RISHA	0.79366	-0.42395	0.55814	0.75018	0.48083	0.45456	0.45234
RUSPIN	0.28748	0.89682	0.57786	0.66123	0.41732	0.32327	0.36575
BRIKON	0.53616	-0.12637	0.59544	0.00000	0.77114	0.82998	0.81340
RISHA	11.15086	-7.00795	10.67724	6.99169	6.49596	8.97752	3.47397
RUSPIN	4.03909	14.82451	11.05450	6.16268	5.63800	6.38460	2.80894
BRIKON	7.53303	-2.08891	11.39085	0.00000	10.41804	16.39218	6.24690
MAX	4.03909	14.82451	10.67724	0.00000	5.63800	6.38460	2.80894
MIN	11.15086	-7.00795	11.39085	6.99169	10.41804	16.39218	6.24690
D+	24.16648085	RISHA	D-	8.86331			RISHA
	6.174215507	RUSPIN		25.7459			RUSPIN
	20.82307522	BRIKON		9.28275			BRIKON
Alternative	Preference (V)	Ranking					
RISHA	0.26834307	3					
RUSPIN	0.80657319	1					
BRIKON	0.308337386	2					

Within the panel price criterion, RISHA emerged as the most cost-effective option at USD 1,499, followed by RUSPIN at USD 1,552 and BRIKON at USD 1,599.2. BRIKON demonstrated superior performance in material waste, achieving a value of 0, which was lower than RUSPIN's (913) and RISHA's (1,176). Regarding load capacity, RUSPIN distinguished itself with a value of 0.46, signifying that its panels were more transportable than those of RISHA (0.53) and BRIKON (0.85), thereby enhancing transportation efficiency.

Regarding construction duration, RUSPIN demonstrated the most rapid completion time of 7.19, surpassing RISHA at 10.11 and BRIKON at 18.46. In terms of construction expenses, RUSPIN exhibited the lowest cost at USD 339.2, succeeded by RISHA at USD 419.51, whereas BRIKON incurred the highest cost at USD 754.4.

The assessment of the performance distance for each modular prefabricated structural panel technology (RISHA, RUSPIN, and BRIKON) from the positive ideal solution (D+) and the negative ideal solution (D-) indicated their respective advantages and disadvantages. The MAX values indicated the optimal performance for each criterion, whereas the MIN values reflected the minimal performance attainable. In the criterion of room area relative to the standard, RUSPIN attained the maximum value of 14.82451, whereas RISHA recorded the minimum value of -7.00795, demonstrating that RUSPIN surpassed RISHA in adhering to space standards.

Conversely, RISHA exhibited a considerably elevated D+ value of 24.17, signifying a substantial divergence from the positive ideal solution, while its D- value of 8.86 was nearer to the negative solution. This indicated that RISHA's performance was suboptimal in comparison to RUSPIN and BRIKON. BRIKON, exhibiting a D+ value of 20.82 and a D- value of 9.28, is situated between RUSPIN and RISHA regarding overall performance.

The TOPSIS analysis revealed that RISHA attained a preference value (V) of 0.2683, securing third place. RUSPIN, possessing a preference value (V) of 0.8066, secured the top rank, indicating that RUSPIN was the superior panel according to the specified criteria. BRIKON, possessing a preference value (V) of 0.3083, secured second position. RUSPIN excelled in multiple sub-criteria, including the disparity in net area relative to the minimum required space, gross room space versus net room space, construction costs, and construction duration. RISHA excelled solely in the panel price category; however, when evaluating total expenses, RUSPIN proved to be the superior option. BRIKON excelled in the sub-criterion of waste material; however, it ultimately could not rival RUSPIN. Consequently, RUSPIN was deemed the superior panel for modular prefabricated schools, surpassing both RISHA and BRIKON in design, production, and construction efficacy.

5.4. Proposed Solution Design and Local Adaptation

The proposed solution for modular prefabricated elementary school buildings integrates RISHA, RUSPIN, and BRIKON technologies to address the specific needs of disaster-prone areas in Indonesia. Each technology offers distinct advantages: RISHA is suitable for cost-effective, single-story structures in areas with limited access to heavy machinery, as its lightweight panels facilitate manual installation. RUSPIN, with its interlocking design, is ideal for larger classrooms requiring greater spatial efficiency and stability, making it highly suitable for earthquake-prone zones. BRIKON, offering robust multi-story capability and design flexibility due to its varied panel dimensions, is optimal for areas demanding increased structural strength.

The solution incorporates modular dimensions aligned with Indonesian National Standards, ensuring each classroom meets the minimum area of 56 m^2. Local materials are integrated for non-structural components to reduce costs and support local industries. In post-disaster scenarios, these prefabricated modules enable rapid deployment, minimizing educational disruptions. RISHA’s panels, designed for transport via small vehicles or motorcycles, provide accessibility to remote areas, while RUSPIN’s interlocking mechanism shortens construction time, ensuring schools reopen promptly.

Implementation involves collaboration with local governments, the Ministry of Public Works and Housing, and certified applicators. Training programs for workers, community involvement in planning, and continuous monitoring ensure quality and relevance. Post-occupancy evaluations further refine the approach, aligning with cultural and functional needs. By leveraging the strengths of each technology, this solution offers a sustainable, cost-effective, and resilient design for modular prefabricated school buildings in Indonesia.

6. Conclusions

This study sought to assess the efficacy of three local modular prefabricated panel technologies in Indonesia—RISHA, RUSPIN, and BRIKON—for the construction of modular elementary school edifices. Analyses employing the AHP and TOPSIS methods evaluated the design, production, and construction performance of each panel technology, as well as the sub-criteria affecting these factors.

During the AHP phase, performance weights were established by evaluating several sub-criteria, including net room space relative to the minimum required space according to Indonesian National Standard, gross room space in relation to net room space, panel cost, transport capacity, waste material, construction cost, and construction duration. The AHP analysis indicated that the production criterion held the greatest significance, succeeded by design and construction. Production became the paramount criterion as the quality of each panel—be it RISHA, RUSPIN, or BRIKON—was established during this stage. The panels' quality was essential, as they constituted the primary structural elements of the building.

The comparative analysis of weights from various sources revealed that the backgrounds and roles of each respondent affected their priorities. Applicators generally allocated equal importance to the three criteria, whereas the Ministry of Public Works and Housing, tasked with inspections, prioritized construction performance. This method illustrates the varying interests and obligations in the advancement and execution of modular prefabricated panel technology.

The outcomes of the TOPSIS analysis were employed to prioritize the optimal panels among RISHA, RUSPIN, and BRIKON. RUSPIN achieved the highest ranking, signifying it was the top-performing panel according to the specified criteria. BRIKON secured the second position, whereas RISHA, despite attaining third place, excelled solely in panel cost. Nevertheless, when evaluating total expenses, RUSPIN proved to be the superior option. RUSPIN excelled in various sub-criteria, including net room space relative to the minimum required space according to Indonesian National

Standards, gross room space compared to net room space, construction costs, and construction duration. BRIKON, despite its superior efficiency in waste material, was unable to compete overall with RUSPIN.

Consequently, RUSPIN was identified as the superior panel for modular prefabricated elementary school buildings, exhibiting outstanding performance relative to RISHA and BRIKON in design, production, and construction parameters. The results indicated that while RISHA is the predominant technology, primarily due to governmental backing, RUSPIN more effectively satisfies the requisite standards for reliability and construction efficiency in modular school edifices. It is advisable to contemplate the utilization of RUSPIN in forthcoming school constructions, particularly in disaster-prone regions necessitating rapid and dependable building solutions.

To further enhance the application of modular prefabricated technologies in Indonesia, several recommendations are proposed. First, integrating locally available materials for non-structural components can reduce overall costs, support local industries, and ensure cultural compatibility. Second, modular designs should be tailored to address unique disaster risks, such as floods, tsunamis, and volcanic eruptions, by incorporating features like elevated platforms or water-resistant materials. Third, expanding training and certification programs for applicators and construction workers can improve the quality and efficiency of modular construction while fostering economic opportunities. Fourth, research should focus on developing advanced lightweight materials that combine transportability with high strength for better structural resilience. Lastly, leveraging digital tools, such as Building Information Modelling (BIM), can streamline the design and construction processes, reduce errors, and enhance project management. By addressing these areas, modular prefabricated technologies can be further optimized to meet the diverse needs of Indonesia's regions, ensuring faster, more resilient, and cost-effective construction solutions for educational infrastructure in disaster-prone areas.

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