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Risk Mitigation Based on ISM-MICMAC Method for Subsidized Housing Development in Construction Stage

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Abstract: The development of subsidized housing, which includes a construction process, is inseparable from risks that can hinder development and cause losses. Risks need to be managed and followed up properly and in a structured manner. This study presents a risk mitigation hierarchy for the development of subsidized housing during the construction period. The risks mitigated are major risks that have been analyzed in previous studies, specifically during the construction stage. The risk mitigation hierarchy for the construction stage of subsidized housing development was analyzed using the Interpretive Structural Modeling–Cross Impact Matrix Multiplication Applied to Classification (ISM-MICMAC) integration method. Fifty-five risks were identified at the construction stage, and five of them are major. Twelve mitigations are arranged based on the estimated impacts they will cause. The relationship between mitigation variables is analyzed using the ISM method followed by analysis using the MICMAC method. Five levels of hierarchy with a total of fifty- five contextual relationships between variables are spread across three quadrants on the MICMAC diagram: driver/independence linkage, and dependence. No mitigation falls into the autonomous quadrant. Mitigations that falls into the driver/independence category equals six, the linkage quadrant equals two, and the dependence quadrant equals four. Three hierarchical pathways divide the five levels of hierarchy, each with its driver for mitigation. The first path involves selecting competitive suppliers and construction cost efficiency including innovation in materials and technology. The second path is establishing structured communication between project parties. The third path is to maximize the bank credit ceiling. This risk mitigation model is expected to provide input to reduce or eliminate risks for subsidized housing developers during the construction stage.

Keywords: risk, mitigation, ISM, MICMAC, subsidized housing, developer, construction stage.

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1. Introduction

Home ownership for every citizen is one aspect that reveals a country's economic level. However, not every community can afford a dream home, especially for low- income individuals. The development of subsidized housing is a government effort to meet the housing needs of low-income individuals (Odoyi and Riekkinen, 2022; Shittu et al., 2022). Many developing countries implement this initiative as a social program to promote economic sector improvements (Akinsulire et al., 2024). In Indonesia, the government has planned to develop one million subsidized houses each year (Syukry et al., 2022). This ambitious goal aims to alleviate the housing shortage faced by many families and enhance living conditions nationwide. By providing affordable housing options, the government aims to enhance the overall quality of life and promote economic stability for low-income households. This presents a significant business opportunity for housing developers due to increasing demand. The housing development program is expected to impact other industries, including the construction and financial sectors (Rahmawati and Rukmana, 2022).The development of subsidized housing is certainly adifficult task, and developers face several challenges. The challenge of developing subsidized housing is providing houses at low prices that are functionally feasible, comfortable to live in, and profitable (Ram and Needham, 2016). The availability of land, building materials, and human resources greatly determines the success of subsidized housing development. The demand for housing is higher in urban areas due to the phenomenon of urbanization; however, suitable land is difficult to acquire and the price is high. The cost of building materials increases every year due to unpredictable inflation (Emanuel and Prayogo, 2023; Musarat et al., 2020). The cost and quality of construction work are also greatly influenced by the skills of human resources and their wages (Karimi et al., 2018; Pribadi and Chan, 2022).

The developer must anticipate this problem during the construction period and implement risk management. As with all construction projects, managing risks that may become obstacles is crucial for achieving project success (Godfrey, 1996). Housing construction projects have more complex risks compared to other construction projects (Rumimper, Sompie, and Sumajouw, 2015). Risks that often affect construction projects are usually unpredictable and include inflation, changes in government regulations and policies, and poor design and engineering errors (Siraj and Fayek, 2019). One effect of inflation impacting the development of subsidized housing is the high price of houses, which remains elevated due to both high land prices and construction costs (Gabbe, 2018). The developer also needs to identify changes in government policy, community acceptance, financial and managerial factors, as well as other relevant issues (Adabre et al., 2022; Schuetz, 2020; Voronina and Steksova, 2020). Risks must be identified at various steps and times so that mitigation actions can be planned to reduce, move, or avoid them (Flanagan and Norman, 1993).

Mitigation is an effort to reduce the impact of identified risks that cause losses. Mitigation methods, based on impactful risks, should be carried out systematically from the most influential to the most affected. To ensure the effective and efficient implementation of mitigation, a specific method must be utilized to analyze the decision-making process. There are several methods for analyzing decision-making based on hierarchical processes, including the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Decision-Making Trial and Evaluation Laboratory (DEMATEL), and Interpretive Structural Modeling (ISM). The AHP method is straightforward to use for simple and clear hierarchical structures, but it cannot handle interdependencies between elements and is prone to inconsistencies. The ANP method can handle more complex systems than the AHP method, taking into account reciprocal relationships and dependencies, but has the disadvantage of requiring specialized software and challenging interpretation of results (Y. Li and Wang, 2019). The DEMATEL method is used to construct cause-effect relationships and is often used to construct ANP structures, but if not carefully applied, the interpretation can be subjective. The ISM, which handles more complex systems for exploration and relationships between elements based on transitivity, results in a clearer hierarchy map. The ISM method is used to understand the relationship between variables within a system, including construction projects (Chen, Li, and Zha, 2024; Dandage et al., 2018). The relationship and influence of one variable against another will make it easier to organize it and make the right decisions. The ISM method is also often combined with the Cross-impact multiplication applied classification (MICMAC) matrix method. ISM provides the results of the relationship between variables and arranges them in several hierarchical levels, while MICMAC groups them into quadrants including influential, uninfluential, related, and affected variables.Several studies utilizing the ISM-MICMAC integration method have successfully mapped and identified key risk factors. For example, Wu et al. (2023), examined the causes of accidents in subway projects and identified key factors such as poor geological conditions, unstable psychological states, inadequate safety training, natural disasters, and incomplete management systems. Fan, Binchao, and Yin (2023), studied factors influencing delays in prefabricated building project scheduling, and identified key risk factors– such as contractor experience, the application of new technologies, and complete standards. Toulabi, Pourrostam, and Aminnejad (2024), examined factors for mitigating safety risks in mass housing projects and identified management commitment as a key factor. Zhao et al. (2025), examined factors influencing the quality of prefabricated steel structure houses and identified three levels of quality control to avoid quality defects. The combination of the ISM-MICMAC method is often used in the hierarchical analysis of a system to provide an overview of the hierarchical relationship between risk factors and mitigation strategies so that it can be used as a reference in decision-making (Guan, Abbasi, and Ryan, 2020; Jung, Lee, and Yu, 2021; S. Li, Huo, and Jiao, 2023).

Plentiful research has been conducted on the risks of subsidized housing development, but many problems remain, particularly the relatively high housing prices for low-income communities despite subsidies, as in Bali, Indonesia. These problems persist due to inadequate risk management. The present study aims to develop a risk mitigation model for subsidized housing developers during the construction stage using the integrated ISM-MICMAC method. The risks studied originate from both internal and external factors from the developer's perspective. The model created using the integrated ISM-MICMAC method organizes information in a clear order, illustrates how different factors relate to each other, and identifies which factors are most important. The mitigation model generated in this study provides input to developers on how to make structured decisions, starting with executing key mitigations followed by other mitigations according to the hierarchical flow. This model can guide developers in preventing and eliminating risks in a targeted manner when developing subsidized housing.

2. Research Method

2.1. Risk Identification

Initial subsidized housing development risk identification was determined based on a literature study, which was then developed through direct observation of the developers (subjects). Risk identification was based not only on internal factors but also on external factors. External risks stem from political, economic, social, technological, legal, and environmental (PESTLE) aspects, while internal risks stem from financial, design, technical, and management aspects (Rastogi and Trivedi, 2016; Tessema, Alene, and Wolelaw, 2022). The initial risks were derived from various previous research studies in which these risks were investigated in construction projects, particularly within the housing sector and other related construction areas. Table 1 displays the identified risks along with their corresponding references. The identified risks are then compiled in a questionnaire and assessed by respondents from subsidized housing developers. The number of respondents consisted of twenty subsidized housing developers who are members of the Real Estate Indonesia (REI) Association and *Himpunan Pengembang Permukiman dan Perumahan* (HIMPERRA) in Bali, Indonesia.

2.2. Risk Analysis

Respondents assess the level of likelihood and consequence on a scale of one to five , where values close to one are for improbable or negligible values and values close to five are for frequent or catastrophic values. The risk assessment data from respondents is then analyzed to obtain the level of risk acceptance (X) by multiplying the likelihood mode (F) by the consequence mode (K) following Eq. (1). The level of risk acceptance is categorized into four categories: , namely negligible ($X \leq 2$), acceptable ($3 \leq X < 5$), undesirable ($5 \leq X \leq 12$), and unacceptable ($X > 12$). After determining the level of risk acceptance, it is further categorized into two groups: minor risks, which include negligible and acceptable levels, and major risks, which include undesirable and unacceptable levels (Godfrey, 1996).

$$X = F \cdot K \tag{1}$$

The major risks that occur during the subsidized housing development phase are first predicted, and their impacts are then followed by mitigation strategies based on the principles of risk elimination, transfer, and avoidance (Flanagan and Norman, 1993; Godfrey, 1996). The determination of mitigation strategies is also carried out based on input from developers combined with literature studies. Additionally, this mitigation strategy will be examined using the ISM-MICMAC method, which begins by determining how the different elements relate to each other, with input from expert practitioners. This is followed by creating the Structural Self-Interaction Matrix (SSIM), Reachability Matrix (RM), Cross-Impact Multiplication Applied Classification (MICMAC) matrix, and finally determining its hierarchical structure. This hierarchical structure will help in identifying the most influential factors and their interdependencies, guiding the development of effective mitigation strategies.

2.2. Interpretive Structural Modelling (ISM)

Interpretive Structural Modeling (ISM) is a method of identifying factors in a system and analyzing their relationships. The analysis of risks and impacts determines the relationship between the mitigation elements in this study. The mitigation elements that are collected are then reviewed for their relevant and contextual relationships by expert practitioners. The expert practitioners who review them are senior practitioners who have lengthy experience in subsidized housing development. After the relationship between elements is reviewed and determined, the next step, with the help of professional ISM software (accessible via the link https://statistikawanku.shinyapps.io/ism_software/), is to determine the reachability matrix so that its hierarchy can be determined (Anand and Bansal, 2017). The steps of the ISM method analysis are explained in the next section.

2.2.1. Structural Self-Interaction Matrix (SSIM)

The relationship of the elements studied by expert practitioners is then arranged in a self-interaction matrix structure (SSIM). The SIM matrix shows the pairwise relationship between elements expressed by the symbols *V*, *A*, *X*, and *O*. The paired elements are expressed by variables (*I* and *j*). The symbol "*V*" indicates the relationship between variable *i* affecting *j*. The symbol "*A*" indicates that *j* affects *i*. The symbol "*X*" indicates a two-way relationship and mutual influence between the variables *i* and *j*. Finally, the symbol "*O*" indicates that there is no relationship or influence from variables *i* or *j*. SSIM is the basis for compiling the reachability matrix to obtain the relationship between the analyzed elements.

2.2.2. Reachability Matrix (RM)

Next, the SSIM matrix was converted into a binary matrix, transforming it into an Initial Reachability Matrix (IRM). Binary numbers (0 and 1) express the reachability matrix, indicating its non-connection and connectivity, respectively. The conversion of the symbol *V*, which is the row, affects the column: $(i,j) = 1$ and $(j,i) = 0$. The symbol A in the column affects the row, $(i,j) = 0$ and $(j,i) = 1$. Then, the symbol *X*, demonstrates the relationship between rows and columns that influence each other, $(i,j) = (j,i) = 1$. Finally, the symbol *O*, indicates that there is no relationship between rows and columns, $(i,j) = (j,i) = 0$.

After the initial reachability matrix is composed, the transitivity check is continued. The transitivity check ensures the consistency of the relationship between elements that are not directly related through the relationship between other elements. The indirect relationship check is shown where R[i][j] = 1 and R[j][k] = 1, then R[i][k] is also 1. This indirect relationship is also called transitive closure, which can be solved by general methods, such as the Floyd-Warshall Algorithm, namely R [i][k] = R [i][k] ∨ (R [i][j] ∧ R [j][k]). Each relationship between elements in the matrix is repeatedly processed until it shows whether each element can be reached directly or indirectly. Then, the result is presented in the Final Reachability Matrix (FRM).

Based on the final reachability matrix, elements can be divided into several different levels in the system by analyzing the reachability set (Ri) and the antecedent set (Ai). The reachability set (Ri) is an element that can be reached by element i, while the antecedent set (Ai) is an element that has a path to element i. The next step is to find the interaction Ri ∩ Ai of each element. When Ri equals Ai, the element reaches its highest level and becomes eligible for removal from the analysis. This process is repeated for each remaining element, and each element then obtains its respective level.

2.2.3. Matrix Cross-Impact Multiplication Applied Classification (MICMAC)

ISM uses the MICMAC method to analyze the relationship between elements and their level of influence in a system. This method will group the elements based on their Driving Power (DP) and Dependency Power (D). Driving power and dependency power are each calculated by summing the row and column values in the reachability matrix. After obtaining its driving power and dependency power values, each element is categorized into four groups: autonomous, dependent, linked, and independent/driving. Autonomous is an element with low driving power and low dependency, or an element that has minimal influence on the system. Dependence is an element that possesses low driving power but exhibits high dependency, or it is subject to the influence of other elements. Linkage is an element with high driving power and high dependency and is also called a critical element because it is dependent on other elements and also influences other elements. Finally, independence/driving is an element characterized by high driving power and low dependency, making it a key element that influences other elements. MICMAC is depicted in the form of a scatter diagram with four quadrants where the X-axis is dependence power and the Y-axis is driving power, as well as four main quadrants.

2.2.4. Risk Mitigation Hierarchy Structure Of Subsidized Housing Construction Stage

After determining all levels and relationships between elements and obtaining their categories, the next step is to arrange the mitigation elements in a hierarchy chart. The hierarchy chart illustrates a risk mitigation model that aids in decision-making regarding risk mitigation strategies during the subsidized housing construction stage, prioritizing those that are the most effective and impactful.

3. Results and Discussion

3.1. Risks and Mitigation of Subsidized Housing Construction Stage

A total of fifty-five risks were identified during the construction stage, spread across all sources, both internal and external. The results are presented in Table 1, organized by external and internal factors, followed by their sources. The identified risks were then compiled into a questionnaire for further assessment by respondents.

Table 1. Risk Identification, Source, and References

Code	Risk Identification	Source	References
R1	Demonstrations and extortion at project locations/illegal levies	Social	(Rumimper, Sompie, and Sumajouw, 2015)
R2	Riots	Social	
R3	Sabotage	Social	
R4	Difficulty in implementing new/special technology	Technology	
R5	Limited building materials/materials in the market	Economy	Interview
R6	Monetary instability	Economy	Interview
R7	Changes in exchange rates	Economy	(Siraj and Fayek, 2019)
R8	Material price inflation	Economy	(Adabre et al., 2022; Musarat et al., 2020; Partamihardja, 2014)
R9	Untimely payment methods	Economy	(Partamihardja, 2014; Rumimper, Sompie, and Sumajouw, 2015)
R10	Fluctuations in interest rates for bank loans and taxes	Economy	(Gozali, Setiawan, and Nugraha, 2020; Rumimper, Sompie, and Sumajouw, 2015; Siraj and Fayek, 2019)
R11	Large 'coordination' costs with residents around the project	Economy	(Susanto, 2020)
R12	Hindered disbursement of subsidized mortgage funds from banks after the contract process is carried out	Economy	(Rumimper, Sompie, and Sumajouw, 2015; Susanto, 2020)
R13	Domestic political instability,	Politic	(Adabre et al., 2022)
R14	Changes in government policy	Politic	(Hidayat, Malahayati, and Bulba, 2021; Rumimper, Sompie, and Sumajouw, 2015)
R15	Environmental regulations that hinder construction	Environment	(Hidayat, Malahayati, and Bulba, 2021)
R16	Environmental pollution and contamination,	Environment	
R17	Force majeure (earthquakes, landslides, fires, and floods)	Environment	(Hidayat, Malahayati, and Bulba, 2021; Rumimper, Sompie, and Sumajouw, 2015)
R18	Disagreement in evaluating contract price revisions	Legalities	(Rumimper, Sompie, and Sumajouw, 2015)
R19	Breach of contract	Legalities	

Table 1. Risk Identification, Source, and References (continued)

Code	Risk Identification	Source	References
R20	Disputes in the contract	Legalities	(Hidayat, Malahayati, and Bulba, 2021)
R21	Delay in settlement of contract disputes	Legalities	
R22	Splitting certificate and splitting building permit late in the early period of the project	Legalities	(Susanto, 2020)
R23	Cash flow is stuck	Financial	(Rumimper, Sompie, and Sumajouw, 2015; Voronina and Steksova, 2020)
R24	Emergence of large extra costs during implementation	Financial	(Gabbe, 2018; Hidayat, Malahayati, and Bulba, 2021; Voronina and Steksova, 2020)
R25	Lack of marketing	Financial	(Partamihardja, 2014; Susanto, 2020)
R26	Design and scope changes	Design	(Rumimper, Sompie, and Sumajouw, 2015)
R27	Incomplete design/ drawings	Design	(Siraj and Fayek, 2019)
R28	Incomplete equipment	Design	(Rumimper, Sompie, and Sumajouw, 2015)
R29	Equipment that is no longer feasible	Design	
R30	Delay in equipment delivery	Design	
R31	Equipment misplacement	Design	
R32	Limited materials	Design	
R33	Poor material quality	Design	(Voronina and Steksova, 2020)
R34	Waste of materials	Design	(Rumimper, Sompie, and Sumajouw, 2015)
R35	Delay in material delivery	Design	
R36	Excess use of materials (waste material)	Technical	
R37	Material and building structures damages	Technical	
R38	Improper material testing	Technical	Interview
R39	Theft of materials	Technical	(Hidayat, Malahayati, and Bulba, 2021)
R40	Use of used materials	Technical	
R41	Failure to complete work due to not being by the contract	Technical	(Tessema, Alene, and Wolelaw, 2022)
R42	Construction method changes	Technical	(Rumimper, Sompie, and Sumajouw, 2015)
R43	Wrong supplier selection	Technical	
R44	Limited number of workers in the field	Technical	
R45	Inappropriate selection of work methods	Technical	
R46	Inability to take quick corrective action	Management	(Tessema, Alene, and Wolelaw, 2022)
R47	Failure communication in the project team	Management	(Rumimper, Sompie, and Sumajouw, 2015)
R48	Disputes between workers	Management	
R49	Lack of worker discipline	Management	
R50	Worker on strikes	Management	
R51	Lack of communication among the parties in the project	Management	(Voronina and Steksova, 2020)
R52	Lack of supervision of contractor and suppliers	Management	(Rumimper, Sompie, and Sumajouw, 2015)
R53	Lack of control over work schedules	Management	
R54	High worker change	Management	(Gozali, Setiawan, and Nugraha, 2020)
R55	Poor safety work procedures	Management	(Rumimper, Sompie, and Sumajouw, 2015)

3.2. Risk Analysis

The respondents' assessments were then analyzed for risk following Eq. (1). The respondent assessment data were tested for validity and reliability using SPSS software. Table 2 presents the respondents' assessment data and the results of the risk analysis. The data presented are the frequency of respondents choosing the same value (f) and the mode value (F or K), while the risk acceptance level (X) is the result of multiplying the likelihood mode (F) and the consequence mode (K). The risk analysis results show that there are five risks categorized as major with an undesirable acceptance level. The major risks come from external factors, namely the economic aspect, while the internal factors come from the financial and management aspects. The risks that come from the economic aspect are an increase in material prices (R8), and fluctuations in interest rates for bank loans and taxes (R10). These external factors cannot be controlled directly due to being determined by external parties and are highly dependent on global economic conditions. The internal risks related to finance include a lack of marketing (R25), whereas management-related risks involve workers on strike (R50), and lack communication among the parties involved in the project (R51). The impacts of these major risk categories were then identified, and mitigation strategies were developed.

Table 2. Risk analysis

Risk Code	Likelihood		Consequences		X	Risk Acceptance	Risk Code	Likelihood		Consequences		X	Risk Acceptance
	f	F	f	K				f	F	f	K		
R1	11	2	9	2	4	Acceptable	R29	10	2	8	2	4	Acceptable
R2	8	2	9	2	4	Acceptable	R30	9	2	7	2	4	Acceptable
R3	8	2	9	2	4	Acceptable	R31	11	2	11	2	4	Acceptable
R4	9	2	8	2	4	Acceptable	R32	8	3	9	3	9	Acceptable
R5	12	2	12	2	4	Acceptable	R33	10	2	9	2	4	Acceptable
R6	8	2	8	2	4	Acceptable	R34	9	2	7	2	4	Acceptable
R7	9	2	8	2	4	Acceptable	R35	13	2	11	2	4	Acceptable
R8	10	2	9	3	6	Undesirable	R36	12	2	11	2	4	Acceptable
R9	11	2	9	2	4	Acceptable	R37	9	2	8	2	4	Acceptable
R10	10	2	9	2	4	Undesirable	R38	8	2	7	2	4	Acceptable
R11	12	2	10	2	4	Acceptable	R39	9	2	8	2	4	Acceptable
R12	9	2	10	2	4	Acceptable	R40	9	2	9	2	4	Acceptable
R13	10	2	9	2	4	Acceptable	R41	12	2	11	2	4	Acceptable
R14	11	2	11	2	4	Acceptable	R42	11	2	10	2	4	Acceptable
R15	9	2	9	2	4	Acceptable	R43	11	2	10	2	4	Acceptable
R16	10	2	10	2	4	Acceptable	R44	11	2	10	2	4	Acceptable
R17	13	2	14	2	4	Acceptable	R45	9	2	8	2	4	Acceptable
R18	9	2	9	2	4	Acceptable	R46	10	2	9	2	4	Acceptable
R19	12	2	12	2	4	Acceptable	R47	10	2	9	2	4	Acceptable
R20	13	2	12	2	4	Acceptable	R48	11	2	9	2	4	Acceptable
R21	8	2	10	2	4	Acceptable	R49	11	2	10	2	4	Acceptable
R22	6	2	7	2	4	Acceptable	R50	8	2	7	3	6	Undesirable
R23	7	2	6	2	4	Acceptable	R51	5	3	5	2	6	Undesirable
R24	10	2	8	2	4	Acceptable	R52	7	2	7	2	4	Acceptable
R25	8	3	7	2	6	Undesirable	R53	8	2	8	2	4	Acceptable
R26	7	2	6	2	4	Acceptable	R54	7	2	8	2	4	Acceptable
R27	11	2	10	2	4	Acceptable	R55	6	2	8	2	4	Acceptable
R28	9	2	7	3	6	Acceptable							

3.3. Risk Mitigation

The impacts include decreased profits and efforts to replace materials that negatively affect work quality. This process should consider the use of technology and material innovation (Paikun et al., 2023). Meanwhile, the risk of internal factors results from finance, namely less massive marketing. Slow house sales led to decreased profits, necessitating the implementation of a promotional strategy (Jaelani, Yuliati, and Sartono, 2023). The next internal risk factor arises from management issues, specifically strikes by workers and poor communication between project parties. The impact resulting from the workers going on strike is a delay in the implementation time, while the lack of communication between parties results in unclear information received between parties. To ensure this impact does not occur, a mitigation strategy is needed, which is formulated based on discussions with developers and literature studies. Twelve mitigation formulas were obtained to prevent the impacts caused by the risks. Table 3 presents the risks, impacts, and mitigation strategies in detail. The ISM method codes E1 to E12 correspond to the formulated mitigation strategies. The relationship between each paired element is based on studies by expert practitioners and arranged in a structural self-interaction matrix (SSIM).

Table 3. Risk impact and mitigation strategy

Risk	Impact	Mitigation	Symbol
Material price inflation	Developer's profit is reduced,	Early material ordering,	E_1
		Minimization production costs,	E_2
	Quality of work is not achieved due to replacement of materials	Replacing different materials but the same quality,	E_3
		Material and time efficiency,	E_4
		Considering suppliers with competitive prices,	E_5
		Construction cost efficiency with material and technology innovation	E_6
Fluctuations in interest rates for bank loans and taxes.	Developer's profit is reduced	Maximizing the bank's credit ceiling	E_7
Lack of marketing	Information to the community target is not achieved	Increasing promotion, discounts, and ease of payment	E_8
Workers on strike	Delay for completion of work	Deliberation with workers,	E_9
		Payment on time,	E_{10}
		Providing incentives to workers	E_{11}
Lack of communication among the parties in the project.	There is unclear information between parties	Build structural communication between parties in the project	E_{12}

3.4. ISM Analysis of Risk Mitigation in the Construction Stage

3.4.1. Completing the SSIM

Expert practitioners review the elements in pairs and then arrange them in an SSIM matrix, as shown in Fig. 1. All elements in the matrix display their relationships with the mitigation elements. The total contextual relationship of the twelve elements is fisty-five, and eleven are not connected with the details of the relationship: V = 25, A = 27, X = 3, and O = 11. Furthermore, the SSIM matrix is converted to a reachability matrix.

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
E_1		V	A	X	A	A	a	V	A	V	V	A
E_2			A	A	A	A	A	V	A	X	V	A
E_3				V	A	A	O	V	O	V	V	A
E_4					A	A	A	V	A	V	V	A
E_5						X	O	V	O	V	V	O
E_6							O	V	O	V	V	O
E_7								V	O	V	V	O
E_8									A	A	O	A
E_9										V	V	A
E_{10}											V	A
E_{11}												A
E_{12}												

Fig. 1. Structural self-interaction matrix

3.4.2. Reachability Matrix

The SSIM matrix that has been compiled illustrating the relationship between elements is then arranged into a reachability matrix. The conversion of symbols in the SSIM matrix into the initial reachability matrix is presented in Fig. 2. The analysis of the reachability matrix follows the transitivity rule using the assistance of the ISM professional program to obtain the final reachability matrix as in Fig. 3. Based on the contextual relationship between elements and the ISM analysis, five levels of the risk mitigation hierarchy structure of subsidized housing development during the construction stage are obtained. Elements E5, E6, and E12 have the largest DP values and occupy the highest level (fifth level). Furthermore, elements E3, E7, and E9 occupy the fourth level. Elements E1 and E4 occupy the third level. Then elements E2 and E10 occupy the second level. Finally, elements E8 and E11 occupy the first level.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1	1	0	1	0	0	0	1	0	1	1	0
E2	0	1	0	0	0	0	0	1	0	1	1	0
E3	1	1	1	1	0	0	0	1	0	1	1	0
E4	1	1	0	1	0	0	0	1	0	1	1	0
E5	1	1	1	1	1	1	0	1	0	1	1	0
E6	1	1	1	1	1	1	0	1	0	1	1	0
E7	1	1	0	1	0	0	1	1	0	1	1	0
E8	0	0	0	0	0	0	0	1	0	0	0	0
E9	1	1	0	1	0	0	0	1	1	1	1	0
E10	0	1	0	0	0	0	0	1	0	1	1	0
E11	0	0	0	0	0	0	0	0	0	0	1	0
E12	1	1	1	1	0	0	0	1	1	1	1	1

Fig. 2. Initial reachability matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	DP	R
E1	1	1	0	1	0	0	0	1	0	1	1	0	6	2
E2	0	1	0	0	0	0	0	1	0	1	1	0	4	4
E3	1	1	1	1	0	0	0	1	0	1	1	0	7	3
E4	1	1	0	1	0	0	0	1	0	1	1	0	6	3
E5	1	1	1	1	1	1	0	1	0	1	1	0	9	2
E6	1	1	1	1	1	1	0	1	0	1	1	0	9	2
E7	1	1	0	1	0	0	1	1	0	1	1	0	7	2
E8	0	0	0	0	0	0	0	1	0	0	0	0	1	5
E9	1	1	0	1	0	0	0	1	1	1	1	0	7	3
E10	0	1	0	0	0	0	0	1	0	1	1	0	4	4
E11	0	0	0	0	0	0	0	0	0	0	1	0	1	5
E12	1	1	1	1	0	0	0	1	1	1	1	1	9	1
D	8	10	4	8	2	2	1	11	2	10	11	1		
L	5	1	2	2	6	6	6	2	4	4	3	5		

Fig. 3. Final reachability matrix, calculation of driving power and dependence power

3.4.3. MICMAC Diagram

The sum of rows and columns in the reachability matrix becomes the DP and D values that are plotted on the MICMAC diagram presented in Fig. 4. In the diagram, five elements can be seen entering the independence quadrant: E5, E6, E12, E9, and E7. Then three elements enter the linkage quadrant: E3, E1, and E4. Furthermore, the remaining four elements enter the dependence quadrant, including E10, E2, E11, and E8. There are no elements that enter the autonomous quadrant. Elements E5, E6, and E12 have the highest driving power and the lowest dependence power values, making them key elements and top priorities at the fifth level of the hierarchical structure (driver/independence quadrant). Next, elements E7, E9, and E3 are at the fourth level, which have the same driving power but different dependence values and enter the independence quadrant. The third level contains elements E1 and E4 in the linkage quadrant, which are critical elements. In the dependent quadrant, elements E2 and E10 are at the second level, and E8 and E11 are at the first level. Elements E2, E8, E10, and E11 are very dependent on other elements, so they occupy the last position of the hierarchical structure. The dependence power value shows how elements that have low values will affect other elements that have higher dependence values at the same level or the next level.

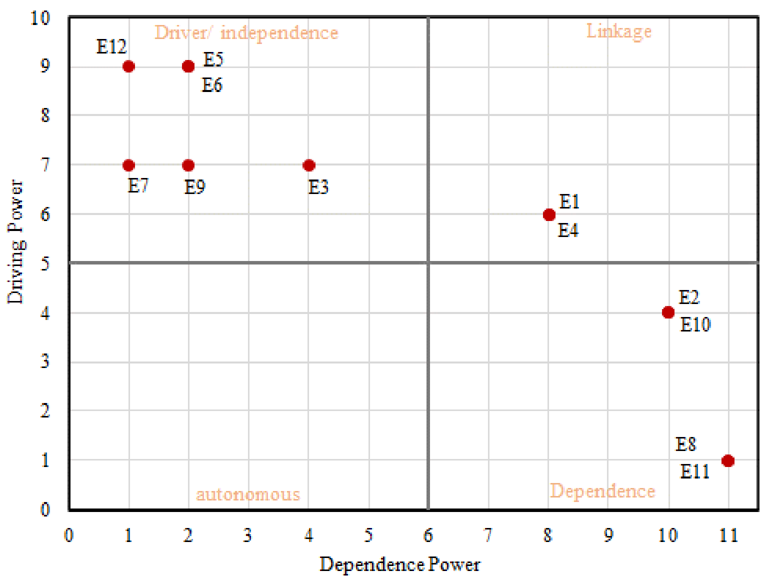

Fig. 4. MICMAC diagram

3.4.4. Hierarchical Risk Mitigation of Subsidized Housing Development at Construction Stage

The ISM method then prepares a hierarchical structure based on the results of the MICMAC analysis. Key elements such as E5 (considering suppliers with competitive prices), E6 (construction cost efficiency with material and technology innovation), and E12 (build structural communication between parties in the project) occupy the highest position and are key to mitigation. After implementing elements E5, E6, and E12, element E3 can be implemented, which involves replacing different materials with the same quality. Additionally, element E9 (talking with workers) can be implemented after a robust communication system is in place between parties (E12). This will then impact elements E1 (ordering materials early) and E4 (using materials and time efficiently). This strategic approach will enhance overall project efficiency and foster a collaborative environment where all parties can contribute to continuous improvement. As elements are implemented, , it is crucial to monitor progress and adjust strategies based on feedback and outcomes. Elements E3, which determines the replacement material, and E7, which maximizes the bank credit ceiling, also influence elements E1 and E4. Elements E1 and E4 affect elements E2 (minimization production costs) and E10 (payment on time) so that elements E2 and E10 can be implemented if efforts E1 and E4 have been made. Finally, elements E11 (providing incentives to workers) and E8 (increasing promotions, discounts, and ease of payment) serve as the final mitigation measures that are implemented after the previous mitigations have been completed. Fig. 5 presents the complete structure of the risk mitigation hierarchy for subsidized housing developers during the construction phase. This hierarchy outlines a systematic approach to address potential challenges, ensuring that each layer of mitigation is effectively applied before moving on to subsequent strategies. By following this structured framework, developers can enhance operational efficiency and improve overall project outcomes in the subsidized housing sector.

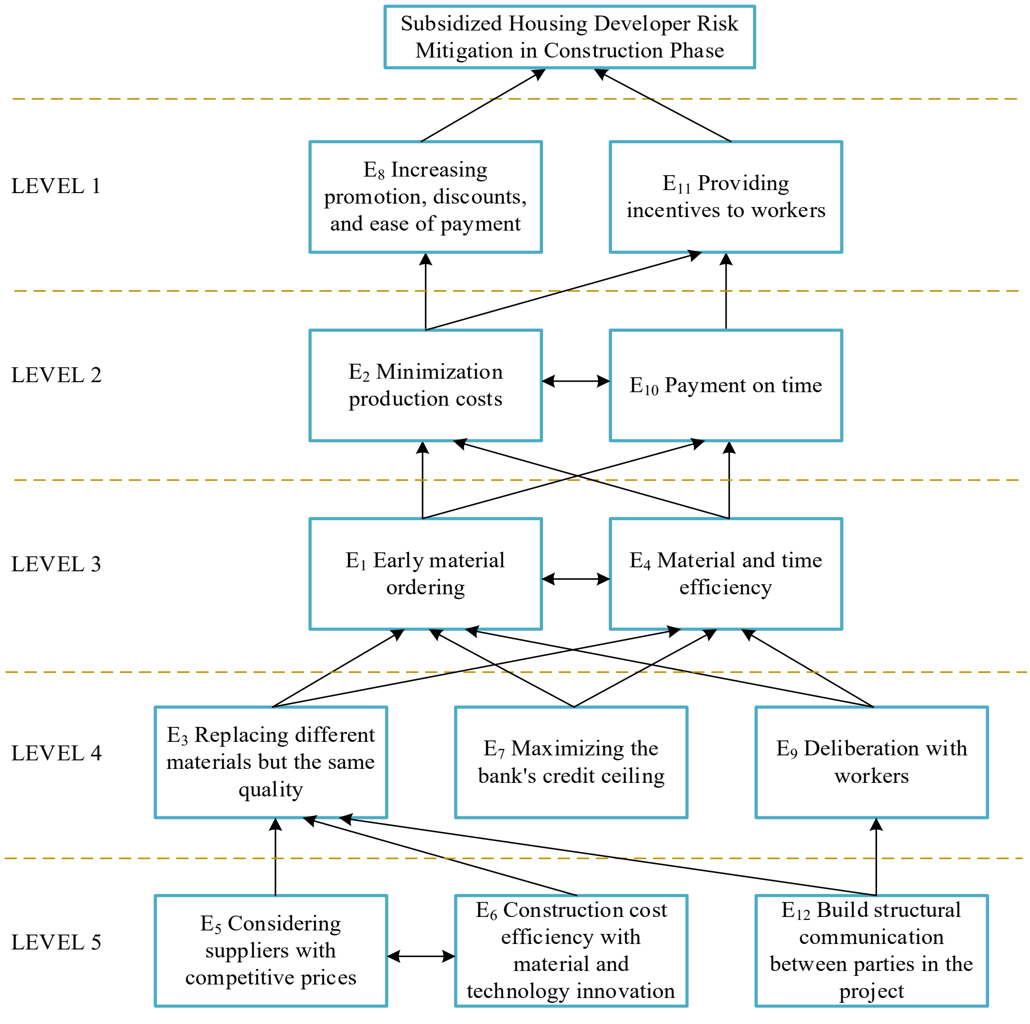

Fig. 5. ISM mitigates risk for subsidized housing developers in the construction stage

3.5. Hierarchical Path Analysis

Based on the ISM structure in Fig. 5, the risk mitigation hierarchy of subsidized housing developers during the construction stage is divided into three parts and three paths. Some paths begin from mitigation elements that are not affected by other elements, such as elements E5, E6, E12, and E7. Mitigation is divided into three parts considering mitigation as a driver, critical mitigation, and affected mitigation. Elements occupying levels one -two indicate driver mitigation, critical parts occupy level three, and levels four and five indicate affected mitigation. Fig. 6, Fig. 7, and Fig. 8 illustrate the division of the hierarchy path.

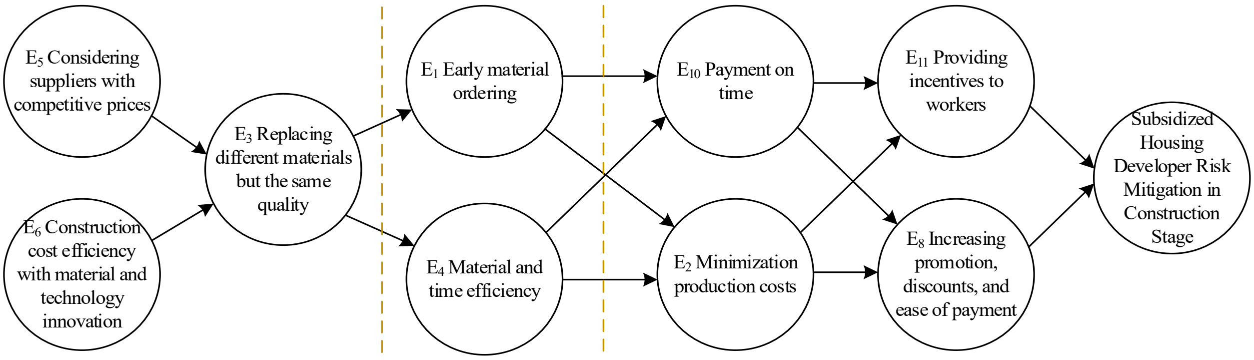

Fig. 6. Hierarchical paths E5 and E6

The first path is mitigation related to determining the use of materials to manage risks caused by rising material prices. As shown in Fig. 6, this path begins by selecting a material supplier who can offer competitive prices while maintaining the same quality. Along with this, a construction implementation method is selected that employs technology and materials designed to enhance construction cost efficiency. Following the selection of a suitable supplier and method, the next step involves deciding to substitute materials with those of similar quality but at lower prices. The subsequent step involves ordering the selected materials, considering their efficiency and construction time. If the previous steps are successfully implemented, production costs can be minimized, and timely payment of workers can be ensured as mitigations. Finally, incentives for workers and increased promotion can be implemented. These results are in accordance with research conducted by Fan, Binchao, and Yin (2023), in which the application of developing technology is one of the key factors in the success of risk mitigation in projects. The application of current technology such as Building Information Modeling (BIM) can also be a solution to detect risk factors in construction projects earlier (Toulabi, Pourrostam, and Aminnejad, 2024).

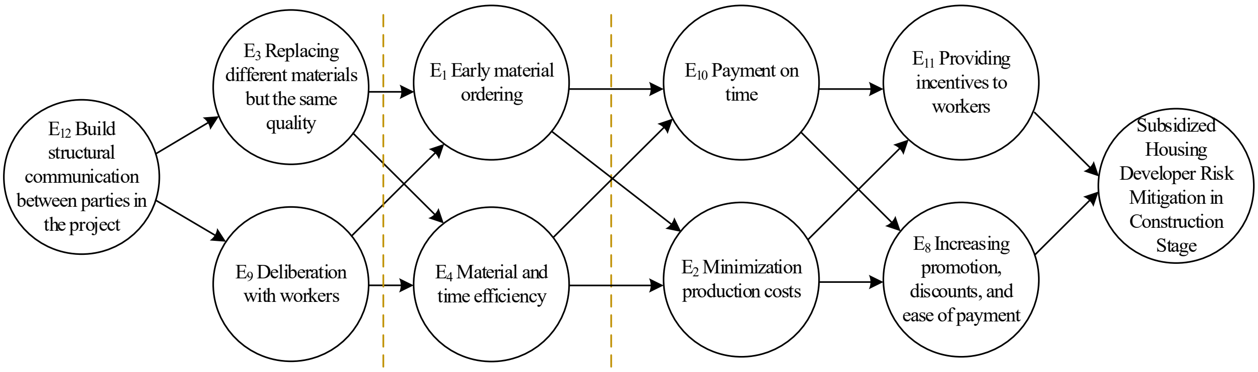

Fig. 7. Hierarchical paths E12

The second path, shown in Fig. 7, begins with building a communication system between parties in the project, such as holding regular scheduled meetings, discussing the project implementation plan, and making notes of the meeting results and distributing them to all parties. Replacement of materials must be communicated in advance and approved before being implemented by the relevant parties. Constraints related to workers can be carried out through deliberation based on the communication system designed to reach an agreement between management and workers. A robust communication system and agreement from all parties will facilitate work in the field to give parties the opportunity to order construction materials earlier, which ultimately increases material and time efficiency. If these stages are successfully implemented, they will be able to facilitate the next stage. Management commitment is a key factor in eliminating risk factors and achieving project success (Toulabi, Pourrostam, and Aminnejad, 2024). One way to implement these principles is by establishing a robust communication system for all project parties. The use of substitute materials requires careful supervision to obtain equivalent quality and can apply the quality control model offered by Zhao et al. (2025).

The final path in the hierarchy is the risk of fluctuations in bank interest rates and taxes. This risk cannot be mitigated directly to influence or change the conditions of bank interest and taxes, but rather, by maximizing funds and times that can be utilized to support construction costs. The amount of funds and times that have been known can be used as a reference for calculating material and time efficiency and ordering materials early. As seen in Fig. 8, the next step is the same as the other paths. The part affected by the implementation of the previous step, which is minimizing production costs and paying workers on time. This is then continued with providing incentives to workers and increasing promotions, discounts, and payments.

The three paths of the subsidized housing developer's mitigation strategy at the construction stage were analyzed using the ISM method combined with the MICMAC method. The analysis of this study's results reveals that the proposed mitigation strategy offers the most effective decision-making hierarchy. The opinions of expert practitioners in determining the contextual relationship between mitigation elements offer the most important points. The results of this analysis are predicted to help developers manage risks during construction to ensure success.

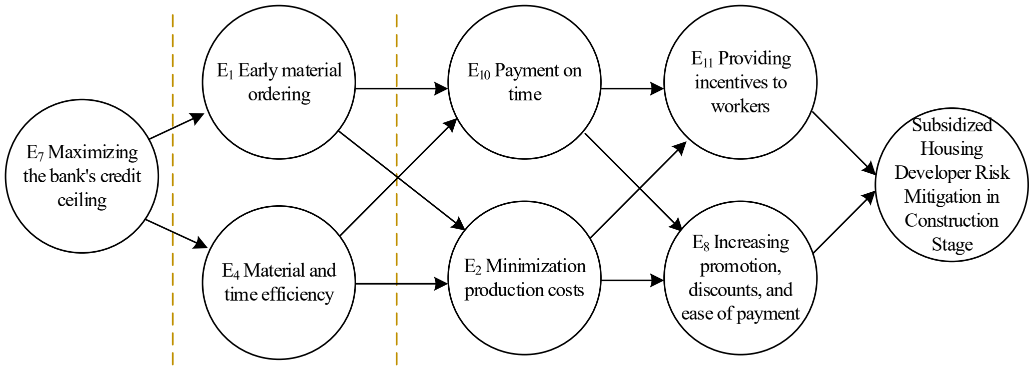

Fig. 8. Hierarchical paths E7

4. Conclusion

This study utilizes the ISM-MICMAC combination method to create a risk mitigation model for subsidized housing developers during the construction stage. There are fifty-five risks identified during the construction stage of subsidized housing developers. The study identifies five major risks, accounting for approximately 9% of the total risks, which require immediate attention and management. The sources of risk come from external and internal factors, specifically economic aspects (external) and financial and management aspects (internal). The formulation of risk mitigation involves interviewing housing practitioners to obtain twelve mitigation strategies. These strategies are designed to address and minimize the impact of identified risks, ensuring the construction process remains on schedule and within budget. By implementing these mitigation measures, housing developers can enhance their ability to navigate challenges and deliver quality subsidized housing projects.

The ISM analysis begins by creating a structural self-interaction matrix (SSIM) with the help of expert practitioners, gathering fifty- five contextual relationships from twelve mitigation strategies. The SSIM matrix is converted into a reachability matrix, and its' transitivity is tested so that the relationship between elements is consistent. Furthermore, based on the final reachability matrix data, specifically the driving power and dependent power of each mitigation strategy, it is plotted on the MICMAC diagram. Twelve mitigation elements are divided into each quadrant: six in the driver/independence quadrant, two in the linkage quadrant, four in the dependence quadrant, and none in the autonomous quadrant. The driving mitigation strategies of subsidized housing developers during the construction stage are: E5 (considering suppliers with competitive prices), E6 (construction cost efficiency with innovation in materials and technology), E12 (build structural communication between parties in the project), and E7 (maximizing bank credit ceilings).

The risk mitigation of subsidized developers during the construction stage is divided into five hierarchy levels. Three paths are generated based on the main drivers of this mitigation, specifically the path of competitive material suppliers and construction methods (material and technology innovation), the path of building communication between parties, and the path of maximizing bank credit ceilings. In addition, the five levels of the hierarchy structure separate into three paths. The developer must actively carry out the first part, known as driver mitigation, involving levels one -two . At this level, the developer's decision and success will affect the subsequent part. . While in the second part, namely level three , which is a critical mitigation that is influenced by the first part and also affects the next part, some specialized action is needed. The last part is levels four and five , which depend on the success of mitigation at levels one -three . These results are predicted to offer guidance to subsidized housing developers in managing construction-related risks.

The Interpretive Structural Modeling (ISM) method is a qualitative approach that produces limited results because it relies heavily on the opinions of the experts involved. Furthermore, the ISM method is static over time, indicating that the relationships between variables may evolve in the future. Further research is needed in different regions and at different times, as the ISM results are still conceptual models that still need to be tested quantitatively, for example using Structural Equation Modeling (SEM).

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Author Contributions

I Gusti Agung Ayu Istri Lestari contributes to conceptualization, methodology, investigation, analysis, data collection, draft preparation, manuscript editing, and research administration. I Dewa Ketut Sudarsana contributes to conceptualization, methodology, data validation, draft preparation, supervision, manuscript editing, and research administration. I Nyoman Yudha Astana contributes to conceptualization, methodology, data analysis, data validation, supervision, manuscript editing, and research administration. Anak Agung Gde Agung Yana contributes to conceptualization, methodology, data analysis, data validation, supervision, manuscript editing, and research administration. All authors have read and agreed with the manuscript before its submission and publication.

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