Integration of Design and Construction Implementation of Buildings on Soft Soil: Decision Support System Model Approach

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ABSTRACT

Construction projects on soft soils face significant technical and financial challenges due to low soil bearing capacity and high potential for settlement. These unique characteristics require effective integration of design and implementation to overcome high risks and improve structural stability. This study develops a Decision Support System (DSS) model based on Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) applied to the process of selecting foundations and construction methods for buildings on soft soils. This DSS enables a comprehensive assessment of various design alternatives and construction methods based on multi-aspect criteria, including stability, cost, time, material, and environmental conditions. Through data analysis and questionnaires involving construction experts, this DSS was tested on an infrastructure project in the tidal area of South Kalimantan. The results show that this DSS model is effective in supporting the selection of foundations, such as piles and bored piles, which are adjusted to the building load and soil conditions. This DSS also provides implementation priorities that can minimize the risk of project costs and delays. In addition to improving efficiency and accuracy in decision making, this model offers an integrated approach that optimizes every stage of construction from planning to field execution. This DSS contributes to the development of better and more sustainable risk management methods in construction projects on soft soils. These findings are expected to be applied more widely in the construction industry, especially in efforts to manage the high risks associated with soft soil conditions and create more efficient and stable construction.

Keywords: soft soil; DSS; AHP; technique; similarity; ideal solution; construction.

INTRODUCTION

Construction projects on soft soil are characterized by high implementation risks and significant construction costs when compared to construction on well-bearing soil [1]. These construction problems are very complex, especially at the planning stage where many design criteria must be applied, especially to the lower structure and ground floor of the building. At the implementation stage, construction equipment and methods must face the challenges of high-risk analysis of costs and time [2], [3]. Several studies have shown that resource risk factors play an important role in the completion time of infrastructure projects on soft soils, including controllable internal risks such as legal and project clients, as well as unmanageable external risks, such as soil conditions and economic factors [4]. Other studies have found that integrated risk management and sustainable construction methods are essential to address these challenges [5], [6].

The challenges in soft ground construction also involve managing risk complexity by introducing a system that supports data-based decision making. [7] developed a risk detection model using global embedding with propagation graph neural network and ensemble learning network method, which showed high performance in risk aspect detection and early detection. Multi-criteria-based decision support systems (DSS) have been widely applied to assess risk and guide decision making. This model supports complex decision making in the context of soft ground construction, which often requires more detailed risk planning and management, and accelerates adaptive and multi-project project scheduling, including agile and hybrid projects that require high flexibility [8].

Studies on DSS have found that the AHP (Analytic Hierarchy Process) method can be an effective

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tool in decision making in construction management, especially in determining priorities for building repairs. [9] used AHP to generate priority vectors for construction elements, while Profile Matching was applied to determine building rankings based on damage volume, damage type, reduction value, and correction factor. This DSS approach allows flexibility in setting repair priorities based on relevant criteria, such as damage volume or available budget allocation.

Construction on soft soil also requires an understanding of foundation design methods that are appropriate for soil conditions that have expansive characteristics. [10] conducted a design comparison for foundations on expansive soft soil, the results of which showed the need for an effective decision support system so that construction management can run in an integrated and sustainable manner. This approach will encourage implementation efficiency and reduce the risk of construction failure due to designs that are not in accordance with field conditions [11]. In addition, research by [12] in Turkey highlighted the need for a comprehensive decision-making model to support sustainable construction. The study highlighted how DSS can help identify and manage various criteria, ranging from project objectives, user constraints, to resource requirements.

As infrastructure projects in areas with soft soil conditions develop, the demand for integrated information systems such as the Building Information Management System (BIMS) is increasing. This model is designed to unify data from various project stages and minimize the risk of discontinuity between planning and implementation. As a tool that can reduce the complexity of projects on soft soil, BIMS is essential to support an integrated management system, minimize the risk of failure, and support sustainable decision making.

This study aims to develop an integrated model for the design and implementation of construction on soft soil with a multi-criteria approach processed through DSS based on AHP and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). DSS helps to prioritize foundations and implementation methods based on different specific conditions in each project, such as soil stability and bearing capacity, which can also help reduce uncertainty in construction costs and schedules. This model allows for a more structured analysis and weighting of technical, environmental, and cost aspects, which allows for better decision making during the planning and implementation stages.

It is expected that the implementation of this DSS model can optimize the decision-making process and improve the efficiency of projects involving soft soil conditions. By integrating DSS into project management, technical and non-technical risks related to soft soil can be anticipated from the planning stage. In addition, this model is expected to provide significant contributions to the development of theory and practice in soft soil construction management, strengthen structural stability, and improve the cost efficiency of more complex projects.

The main contribution of this research is to provide a structured, data-driven, and comprehensive decision support system to assist project managers and stakeholders in facing the challenges of construction on soft soils. In addition, this research also supports innovation in risk management methods, so as to improve project sustainability and answer challenges in frequently changing field conditions. Thus, this DSS-based decision support system can serve as a strategic solution for future sustainable construction projects.

The use of decision support systems (DSS) in the construction management of projects involving soft soil conditions has become an important approach in helping decision makers to deal with the complexity and high risks associated with this type of project [13]. DSS offers data-driven tools capable of analyzing various technical aspects, costs, and environmental conditions. Various multiple criteria-based decision-making methods, such as the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), have been widely used to support better decision-making in the selection of foundation types and construction implementation methods on soft soils [14].

Decision Support Systems (DSS) in Construction

In construction, DSS serves as a tool that is able to identify and assess various alternatives based on a number of different criteria, ranging from soil bearing capacity, cost, to environmental impact.

DSS based on AHP and TOPSIS have proven effective for cases of buildings built on soft soil, where every variable that affects foundation performance must be considered in depth. AHP is used to break down complex decision-making problems into a simple hierarchy that allows decision makers to weigh the criteria and alternatives available [15]. In other words, AHP helps in defining the priority of each criterion in project planning, resulting in a more comprehensive solution in selecting the best construction alternative [14].

In addition, DSS can also help overcome the uncertainties that often arise during the project implementation stage. [7] showed that the use of DSS based on global embedding and propagation graph neural networks can provide more accurate risk predictions in the early stages of a project, so that risks can be better identified and managed. In this case, DSS helps in determining adaptive strategies in dynamic field conditions, especially when there is potential for changes in soil or environmental conditions during the construction process.

Analytical Hierarchy Process (AHP) in Foundation Selection

Analytic Hierarchy Process (AHP) is one of the most widely used methods in DSS for construction projects on soft soil. AHP allows solving problems into a hierarchy, starting from the main objective, criteria, sub-criteria, to available alternative solutions. For example, research by [14] shows that AHP can produce a model that considers various criteria, such as soil conditions, implementation methods, and environmental impacts, which are very relevant for building projects on soft soil. In this study, the highest priority is given to the soil condition factor, which has the greatest influence on foundation stability. The use of AHP in DSS also allows for consistent calculation of priority weights through validity testing using the paired matrix method, which ensures the consistency of the results obtained.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS method serves as a complement to AHP in DSS for soft soil construction. TOPSIS is used to select the alternative that is closest to the ideal solution and farthest from the negative solution. This technique is effective in situations where decision-making must consider several conflicting criteria, such as cost and quality [4]. In the context of building projects on soft soil, TOPSIS facilitates the selection of optimal foundations based on the Euclidean distance from the ideal solution, which is the alternative with the best criteria in terms of soil bearing capacity and long-term stability [16].

In construction projects on soft soil, TOPSIS helps in identifying the most appropriate foundation solutions for dynamic and risky soil conditions. Using AHP and TOPSIS-based DSS models, this study shows that mini-piles and piles are often the optimal choices for light buildings, while bored piles are more appropriate for heavy buildings [17].

DSS Implementation at Planning and Execution Stage

The use of integrated DSS in the planning and construction implementation stages can minimize technical risks that often arise in building projects on soft soil. Research conducted by [10] shows that DSS-based design and construction management methods can optimize project efficiency by reducing the possibility of errors in selecting foundation types that are not in accordance with soil conditions. The implementation of DSS not only helps in risk analysis at an early stage but also in continuous monitoring to manage risks during project implementation [11].

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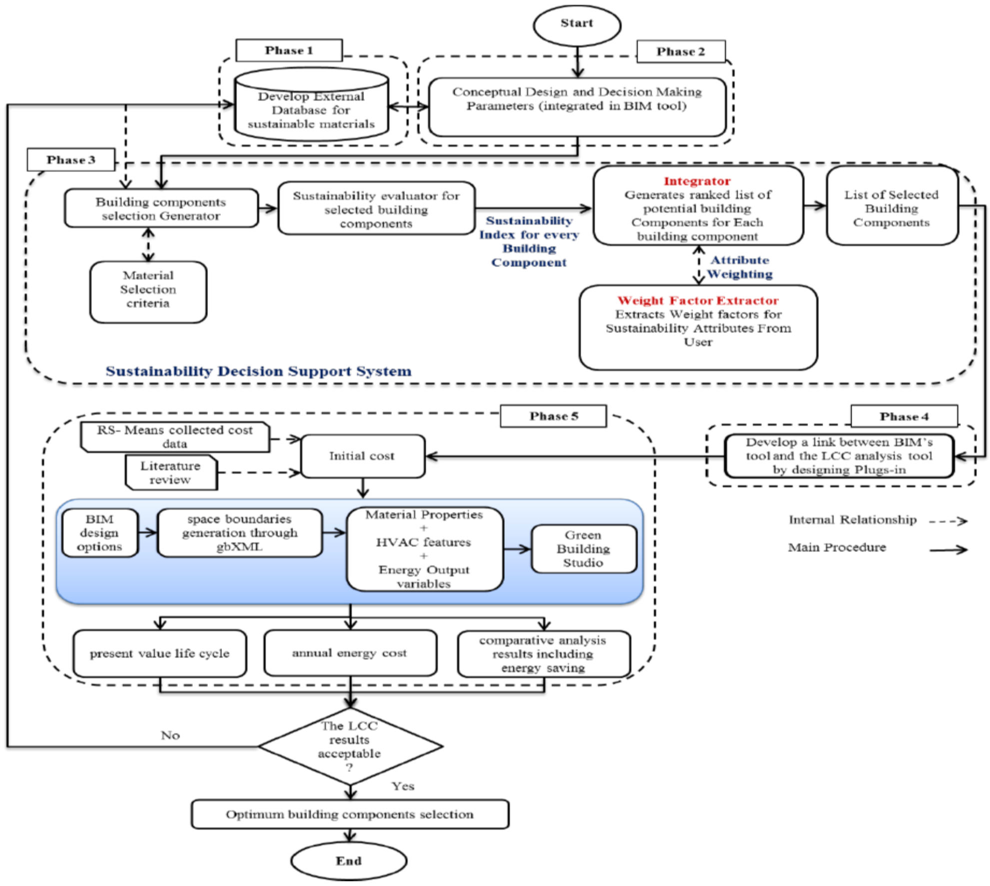

Figure 1. Integration of BIM and DSS

Furthermore, DSS can be integrated with construction information management systems such as Building Information Modeling (BIM) to create a more holistic and data-driven project management system. [17] research states that the integration of DSS with BIM helps in optimizing decisions related to more sustainable building components. BIM-based DSS enables decision makers to design more efficient and sustainable buildings, reduce environmental impacts, and improve the stability of buildings on soft soils.

DSS Case Studies and Practical Applications

The development of DSS for application in projects on soft soils also requires validation through field studies or case studies, such as those conducted by [12] in Turkey. This study used multi-criteria-based DSS to evaluate a number of infrastructure projects and showed that DSS is very helpful in selecting sustainable construction methods. In this study, AHP and TOPSIS-based DSS were applied in selecting foundations that take into account long-term stability and environmental sustainability. This study concluded that DSS can provide practical guidance in dealing with very complex construction problems on soft soils [12].

Finally, various studies have shown that the application of AHP and TOPSIS-based DSS to soft soil construction projects provides significant contributions to increasing efficiency, reducing costs, and building stability. DSS provides analytical tools capable of managing complex aspects of construction management, allowing stakeholders to make more informed and responsive decisions to dynamic field conditions. Thus, DSS integrated into soft soil construction projects is expected to continue to develop as a standard method in supporting data-based decision making in the future.

RESEARCH METHODS

This research was conducted to develop a Decision Support System (DSS) model based on Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in order to support the selection of foundation design and construction implementation methods in building projects on soft soil. The focus of the research is to optimize decision making in the planning and construction implementation stages through the integration of the two methods. The stages of this research method include literature study, data collection, model development, and model testing to validate the effectiveness of DSS in a specific field context.

Research Design

The research design follows a quantitative approach and descriptive analysis. This stage involves identifying key variables and mapping relevant criteria for assessing foundation options. To provide measurable and reliable results, this study uses questionnaire methods and structured interviews with construction experts as well as secondary data collection from relevant literature. The collected data are analyzed to identify variables and criteria weights to be applied to the AHP-TOPSIS-based DSS model.

Place and Time of Research

This research was conducted on building projects in soft soil areas in South Kalimantan, which are known to have peat soil characteristics. The selection of this location was based on challenging geotechnical conditions, which require very precise engineering decisions in choosing foundation methods and implementation strategies. The research was conducted over a period of six months to ensure sufficient field data for model analysis and testing.

Population and Sample

The population of this study were experts in the construction field, especially those who are experienced in handling projects on soft soil. Purposive sampling technique was used to select samples, namely professionals involved in infrastructure projects and have a deep understanding of the risks and construction techniques on soft soil. A total of 30 respondents from geotechnical engineers, structural planners, and project managers were involved in this study to fill out a questionnaire related to the weight of the criteria and alternative foundation designs.

Research Variables

The variables in this study include the main criteria that form the basis for selecting the type of foundation and implementation method, namely:

1. **Soil Conditions**: includes the bearing capacity and stability of the soil.
2. **Implementation Method**: technological readiness and suitability of methods to field conditions.
3. **Cost**: includes construction budget and long-term maintenance costs.
4. **Environment**: environmental impacts that may arise from the selection of foundations.
5. **Resource**: availability of materials and labor required.

Each of these variables is weighted based on expert preferences, which are then processed using AHP to produce a hierarchy of criteria priorities. The resulting DSS model allows for systematic weighting of variables to support the selection of the best alternative in soft soil conditions.

Research Instruments

This study used a questionnaire as the main instrument to collect data from respondents. The questionnaire was designed based on the AHP scale, which includes questions regarding the relative importance of each criterion in selecting the type of foundation and implementation method. This research instrument also includes structured interviews to explore the preferences and experiences of experts related to key variables in risk management in soft soil projects.

Data collection

Primary data were obtained through questionnaires sent to construction experts, while secondary data were collected from relevant literature on the use of DSS, AHP, and TOPSIS in construction

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decision making. Data collected from the questionnaires were processed using SPSS software to ensure validity and reliability, and to ensure that the results obtained were consistent and could be used as a basis for decision making in this study.

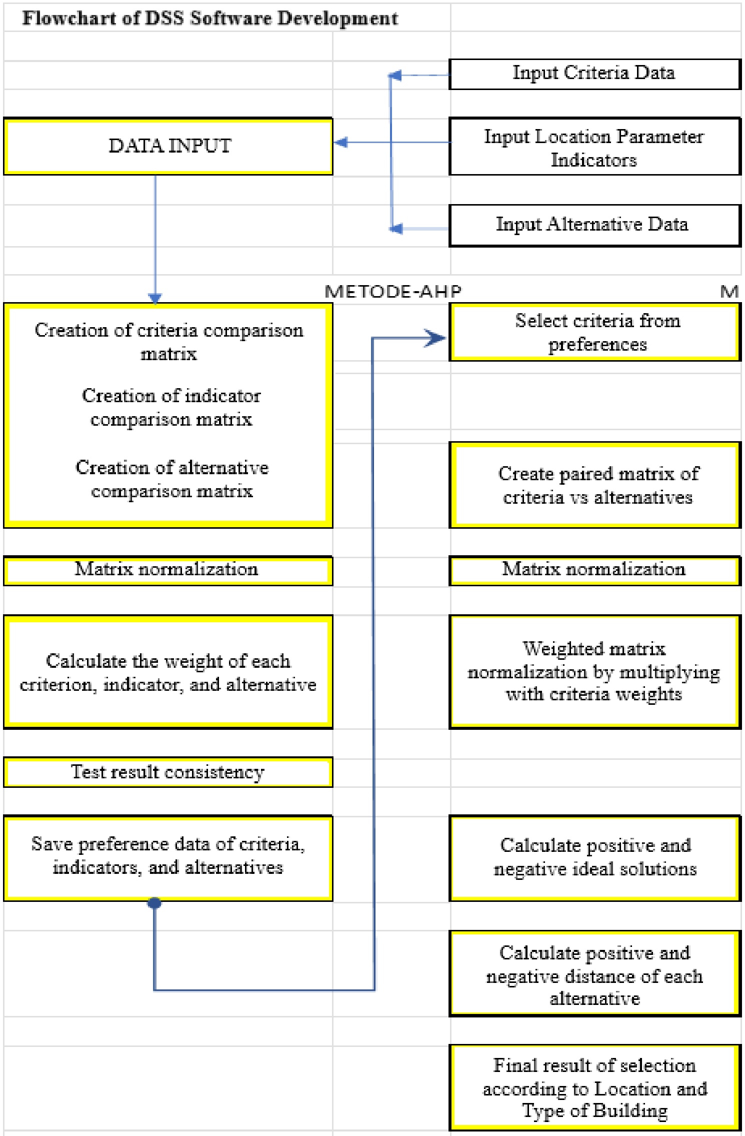
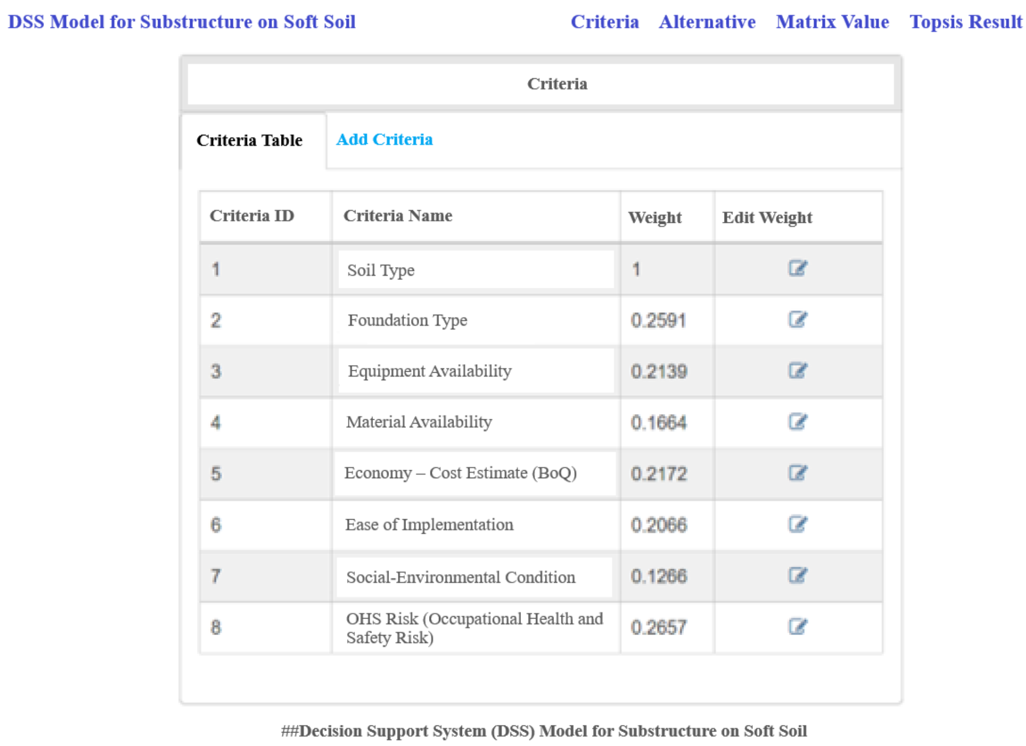


Figure 2. Flowchart of the AHP-TOPSIS model SPK algorithm

Development of AHP-TOPSIS Based DSS Model

The process of developing this DSS model includes several stages, namely:

1. **Criteria and Sub-Criteria Preparation Stage**: Based on the collected data, the main criteria such as soil conditions, implementation methods, costs, environment, and resources are further detailed into sub-criteria. Each criterion and sub-criteria are arranged in a hierarchical form in accordance with the AHP model.
2. **Criteria Weighting with AHP**: AHP is used to calculate the weight of each criterion through pairwise comparison between criteria and sub-criteria. This process produces relative priorities for each criterion in supporting foundation design decisions. Validation of the AHP model is done by calculating the Consistency Index (CI) and Consistency Ratio (CR) to ensure that the respondents' assessments are consistent and the results obtained are valid.



Criteria ID	Criteria Name	Weight	Edit Weight
1	Soil Type	1	
2	Foundation Type	0.2591	
3	Equipment Availability	0.2139	
4	Material Availability	0.1664	
5	Economy – Cost Estimate (BoQ)	0.2172	
6	Ease of Implementation	0.2066	
7	Social-Environmental Condition	0.1266	
8	OHS Risk (Occupational Health and Safety Risk)	0.2657	

Figure 3. Criteria that match the location of the building

3. **Alternative Analysis with TOPSIS**: The TOPSIS method is used to determine the ranking of foundation alternatives based on predetermined criteria. The TOPSIS process includes normalizing the criteria weights, determining positive and negative ideal solutions, and calculating the distance between each alternative and the ideal solution. With TOPSIS, the alternative with the shortest distance to the positive ideal solution and the farthest distance from the negative solution will be selected as the best choice.

Table 1. Determination of Priority Preferences

Alternative Pile Foundation	*Vx*	*Vx*(%)	Priority
The cradle	0.47390	47%	1
Minipile	0.44162	44%	2
Preprint	0.42640	43%	3
Wood	0.42021	42%	4
Non-D-Wall/Raft	0.40617	41%	5
Bore/Strauss Pile	0.39663	40%	6
Partial D-Wall	0.39336	39%	7
Steel	0.37228	37%	8
D-WALL	0.36472	36%	9

DSS Model Testing

The resulting DSS model was tested with a real case trial on a building project in South Kalimantan. Validity testing was carried out by comparing the DSS results with expert decisions manually in several project scenarios. In addition, the reliability of the model was tested using the Cronbach's Alpha method to assess the internal consistency of the weights given to the criteria and sub-criteria.

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The results of the model testing showed that the AHP-TOPSIS-based DSS had a fairly high accuracy in supporting decision making on projects on soft soil.

Practical Implementation

After going through the testing phase, this DSS model is implemented in the form of a web-based software application. This application is designed to be easily accessed and used by decision makers in the field. With comprehensive data integration, this application is able to provide optimal recommendations for the type of foundation and the most appropriate implementation method based on project conditions on soft soil.

Data Analysis and Interpretation

The data obtained from the DSS model testing are interpreted to assess the effectiveness of AHP-TOPSIS in optimizing project decisions on soft soils. The results of this study indicate that the DSS model is able to minimize errors in selecting foundation methods that often occur due to lack of adequate geotechnical data and inconsistencies between planning and implementation. This model has also been proven to reduce technical risks and increase cost and time efficiency in construction in areas with complex soft soil conditions.

RESULTS AND DISCUSSION

The results of the study indicate that the integration of the Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods in a Decision Support System (DSS) is effective in supporting the selection of foundation types and construction implementation strategies for buildings on soft soil. Data collected from 30 construction expert respondents involved in soft soil projects were used to assess the weight of each criterion through the AHP process, which was then processed in the TOPSIS model to obtain the best solution for selecting the most appropriate foundation and implementation method. These results focus on three main components: criteria weighting, foundation alternative ranking, and risk analysis at specific project site conditions.

Criteria Weighting

Through AHP, the most dominant criteria in foundation selection is soil conditions with a weight of around 47.5%. This criterion is the main priority because the stability of the structure is greatly influenced by the bearing capacity of the soil, especially in soft conditions that are susceptible to subsidence and shifting. The second criterion is the implementation method with a weight of 15.3%, which includes technological readiness and implementation capabilities in specific field conditions. Long-term construction and maintenance costs are also important concerns with a weight of 10.5%, followed by environmental impacts (12%) and resource availability (14.7%).

This weighting produces foundation design priorities that are appropriate to the characteristics of soft soil and project conditions, allowing decision makers to identify key factors to consider in decision making. The results of the AHP weighting show consistency with a Consistency Ratio (CR) below 10%, indicating that respondents have good consistency in giving weight to the criteria.

Alternative Foundation Ranking Using TOPSIS

After obtaining the weights from AHP, the DSS model continues the process using TOPSIS to rank the foundation alternatives. Based on the analysis results, pile foundations (mini-piles) and bored piles occupy the top positions as the optimal foundation alternatives for buildings on soft soil. Pile foundations are chosen for light buildings with minimal risk of settlement, while bored piles are more suitable for heavier buildings because of their ability to withstand large loads without causing significant deformation.

Table 2. Ideal solution matrix

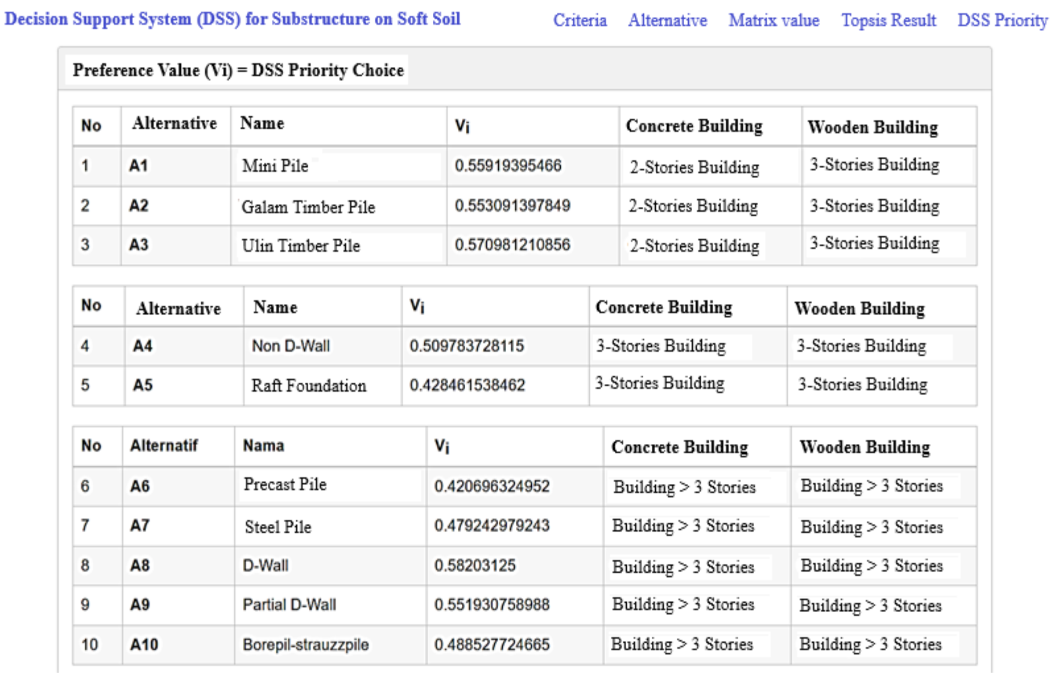
	Criteria		
Soil Type	Foundation Type	Equipment Available	Availability of Materials

Y+	0.1696	0.0985	0.0876	0.0433
Y-	0.0287	0.0639	0.0545	0.0249

Table 3. Distance between ideal solutions and preferences

Alternative	Criteria D+	D-	Vx
Mini Pile	0,22622	0,17892	0,4416
Wood	0,23894	0,17317	0,4202
Timber Pile	0,17964	0,16182	0,4739
Precast	0,24008	0,17847	0,4264
Bore/Strauss Pile	0,24577	0,16155	0,3966
Steel	0,26050	0,15449	0,3723
D-Wall	0,25920	0,14881	0,3647
P-D-Wall	0,25828	0,16748	0,3934
Non-D-Wall/Raft	0,26072	0,17832	0,4062

In the ideal solution distance analysis generated by TOPSIS, mini pile has the smallest distance from the positive ideal solution, indicating that this solution offers the best stability for lightweight buildings. In contrast, bore pile has a higher preference value for heavy buildings, where the risk of soft soil deformation can be better controlled. The ranking obtained through TOPSIS shows flexibility in foundation selection based on specific field conditions.


Decision Support System (DSS) for Substructure on Soft Soil — Criteria | Alternative | Matrix value | Topsis Result | DSS Priority

Preference Value (Vi) = DSS Priority Choice

No	Alternative	Name	Vi	Concrete Building	Wooden Building
1	A1	Mini Pile	0.55919395466	2-Stories Building	3-Stories Building
2	A2	Galam Timber Pile	0.553091397849	2-Stories Building	3-Stories Building
3	A3	Ulin Timber Pile	0.570981210856	2-Stories Building	3-Stories Building

No	Alternative	Name	Vi	Concrete Building	Wooden Building
4	A4	Non D-Wall	0.509783728115	3-Stories Building	3-Stories Building
5	A5	Raft Foundation	0.428461538462	3-Stories Building	3-Stories Building

No	Alternatif	Nama	Vi	Concrete Building	Wooden Building
6	A6	Precast Pile	0.420696324952	Building > 3 Stories	Building > 3 Stories
7	A7	Steel Pile	0.479242979243	Building > 3 Stories	Building > 3 Stories
8	A8	D-Wall	0.58203125	Building > 3 Stories	Building > 3 Stories
9	A9	Partial D-Wall	0.551930758988	Building > 3 Stories	Building > 3 Stories
10	A10	Borepil-strauzzpile	0.488527724665	Building > 3 Stories	Building > 3 Stories

Figure 4. Final Result of TOPSIS Selection

Risk Analysis on Soft Soil Projects

Risk analysis in DSS is carried out by identifying risk factors related to the main criteria, namely soil conditions, implementation methods, and costs. The biggest technical risk is the risk of land subsidence which can cause structural damage. Therefore, mitigating this risk requires a structured approach, including the use of deep foundations that can reduce land subsidence and maintain

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building stability [4].

The AHP-TOPSIS-based DSS model also enables rapid decision-making regarding changing field conditions. With the help of field data integrated into the DSS, decision-makers can reassess foundation choices and construction methods according to conditions that develop during the construction process, such as increased groundwater levels or increased lateral pressures under the foundation. The results of this risk analysis show that the DSS not only provides accurate initial decisions but also allows flexibility for necessary adjustments during the project.

DSS Model Validation and Testing

The developed DSS model was tested on several projects in soft soil areas in South Kalimantan. The test showed that the DSS was able to provide recommendations that were consistent with manual decisions made by construction experts. The accuracy of the model reached more than 90%, indicating that the AHP-TOPSIS-based DSS is effective in supporting decision making for foundation selection in soft soil projects.

To measure the reliability of the model, Cronbach's Alpha test was conducted on the criteria weight, with a result of 0.85, indicating a good level of consistency. This test ensures that the DSS model provides reliable and consistent results in various project scenarios. In addition, this model successfully reduces the potential for errors in decision making due to changes in field conditions and uncertainties that usually arise in soft soil projects.

DSS Model Implementation and Practical Benefits

The developed DSS model has been implemented in the form of a web-based software application, which allows easy access for decision makers in the field. This application is capable of processing real-time data, allowing decision makers to identify optimal solutions according to current project conditions. Through an interactive interface, users can enter specific parameters such as soil type, desired foundation depth, and cost constraints, so that the DSS can provide appropriate recommendations in a short time.

With this DSS, decision makers can be more responsive to changes in field conditions, while minimizing technical risks that often occur due to uncertainty in geotechnical conditions on soft soils. This creates significant cost and time efficiency in project implementation. This DSS model, with the integration of AHP and TOPSIS, offers solutions that are not only technical but also strategic in supporting the sustainability and stability of structures in construction projects on soft soils.

CONCLUSION

This research produces a Decision Support System (DSS) based on Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) that supports decision making in construction projects on soft soil. This model is proven to be effective in helping to select the type of foundation and implementation method by considering the main criteria such as soil conditions, implementation method, cost, environmental impact, and resources. With a structured and consistent approach, this model prioritizes soil conditions as the main criterion, followed by implementation method and cost. The tests conducted showed that the DSS provides more than 90% accuracy in recommending optimal foundations such as piles and bored piles, which are adjusted for light and heavy buildings on soft soil. This model is validated with the Consistency Ratio and Cronbach's Alpha tests, ensuring the level of consistency and reliability in decision making. In addition, the DSS provides flexibility in dealing with changing field conditions, allowing for continuous evaluation that improves structural stability, cost efficiency, and time effectiveness. Several suggestions are proposed for further development. First, the integration of AHP-TOPSIS-based DSS with Building Information Modeling (BIM) or Geographic Information System (GIS) technology will enable real-time data access related to geotechnical conditions and project information. This can support monitoring of soil and structural conditions during construction. Second, to strengthen the validity and reliability of the DSS, it is recommended that this model be tested on various projects in soft soil locations with different characteristics. Cross-site testing will enrich the understanding of the performance of the DSS in various geotechnical conditions. Third, the addition of criteria such as work safety and long-term environmental risks will increase the effectiveness of the DSS in addressing challenges in soft soil projects and strengthen its role in ensuring project sustainability. Finally, the implementation of DSS should be accompanied by training for decision makers and field implementers, so that this technology can be used optimally. Training that emphasizes system understanding and technical risk analysis will make DSS a more useful tool in supporting the success of projects on soft soils. Through the implementation of this suggestion, AHP-TOPSIS-based DSS is expected to be a reliable tool in risk management and decision optimization on soft soil projects, while supporting safer, more efficient, and more sustainable construction solutions.

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