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Material Requirement Prediction System and 2D Visualization of Light Steel Roof Design Using the Decision Tree Algorithm Based on an Expert System

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Abstract

Material requirement planning is a critical aspect of the construction industry, which is increasingly moving toward digital transformation. However, in practice, material estimation for roof construction is still predominantly performed using conventional manual calculations. This approach relies heavily on subjective judgment, resulting in inconsistent estimates and increasing the risk of cost overruns, material waste, and project delays. To address these challenges, this study proposes an expert system-based web application for predicting material requirements and generating two-dimensional (2D) visualizations of light steel roof designs The proposed system employs the Classification and Regression Tree (CART) algorithm, a Decision Tree technique, to classify roof specifications based on building dimensions, while an expert system provides rule-based recommendations for supporting construction materials, including roof sheets, screws, and structural components. Users are only required to input the building length and width, after which the system automatically predicts material quantities, estimates construction costs, and generates a 2D roof design visualization. The integration of predictive analytics and expert knowledge minimizes human error, improves the consistency of material estimation, and enhances decision-making for both technical and non-technical users. Furthermore, the developed system provides a transparent, efficient, and user-friendly solution for construction planning by reducing calculation complexity and optimizing material utilization. The proposed approach demonstrates the potential of combining Decision Tree-based prediction with expert system reasoning to improve the accuracy and efficiency of digital material planning in light steel roof construction.

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1. Introduction

Material requirement planning is one of the most critical processes in construction projects because inaccurate estimation may lead to material shortages, excessive waste, increased costs, and project delays(Hasanah et al., 2021). However, material estimation for light steel roof construction is still commonly performed using manual calculations based on personal experience, making the results inconsistent and susceptible to human error(Nuraeni et al., n.d.).

The development of information systems provides opportunities to automate material estimation and improve planning accuracy(Azmi & Ismail, 2020). A digital system can process construction parameters more efficiently while assisting both technical and non-technical users in determining appropriate building materials and estimating project costs before construction begins(Septiandi et al., 2024).

Decision Tree is one of the most widely used data mining algorithms for classification problems due to its simplicity, interpretability, and high prediction accuracy(Nasional et al., 2023). In particular, the Classification and Regression Tree (CART) algorithm can classify construction requirements based on building dimensions(Kunci, 2024). Nevertheless, previous studies have mainly focused on prediction models without integrating expert knowledge or providing design visualization to support users' decision-making(Apriliani et al., 2024).

This study proposes a web-based information system that integrates the CART algorithm with an expert system to predict material requirements for light steel roof construction(No et al., 2025). Users only need to input the building dimensions, and the system automatically estimates the required materials, predicts construction costs, and generates a two-dimensional (2D) roof design visualization(Sutabri et al., 2022). The expert system complements the prediction model by providing rule-based recommendations for supporting construction materials(Sunatha et al., n.d.).

The proposed system is expected to improve estimation accuracy, reduce human error, minimize material waste, and provide an efficient decision-support tool for construction planning(Pramana et al., 2022). Furthermore, the integration of automatic prediction and 2D visualization enables users to better understand the proposed roof design before project implementation(Analysis et al., 2023).

2. Research Methodolgy

The research design was systematically developed to ensure that the system development process was conducted in a structured manner, starting from problem identification through system design, implementation, and validation. This research framework served as the primary guideline to ensure that each stage was logically connected and contributed to achieving the objectives of the study.

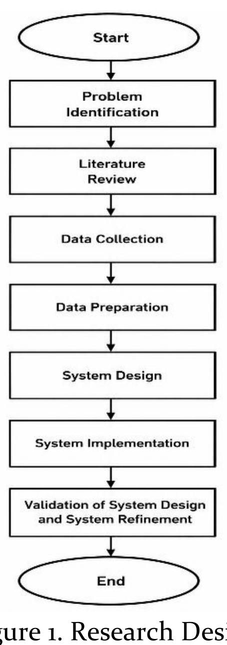


Figure 1. Research Design

As shown in Figure 1, the research consists of six stages: problem identification, literature review, data preparation, system design, system implementation, and system validation. The study begins by identifying the limitations of manual material estimation for light steel roof construction, followed by a review of relevant literature on material planning, the CART algorithm, expert systems, and 2D visualization(Gunawan & Widyassari, 2025). Next, material data are prepared, and the prediction model and expert system are designed. The proposed system is implemented as a web-based application using PHP, MySQL, JavaScript, and HTML5 Canvas. Finally, the system is validated to ensure the accuracy of material prediction, expert rules, and overall functionality.

2.1 System Architecture Design

The system architecture was designed to illustrate the interaction between the main components of the proposed light steel roof material prediction system. As shown in Figure 3.3, the architecture consists of three layers: Client Tier, Logic Tier, and Data Tier. The Client Tier handles user input and displays prediction results, the Logic Tier processes data through the CART prediction model, expert system, and cost calculation modules, while the Data Tier manages the research dataset, material data, pricing information, and prediction results. This three-tier architecture ensures efficient data processing, modularity, and ease of system maintenance.

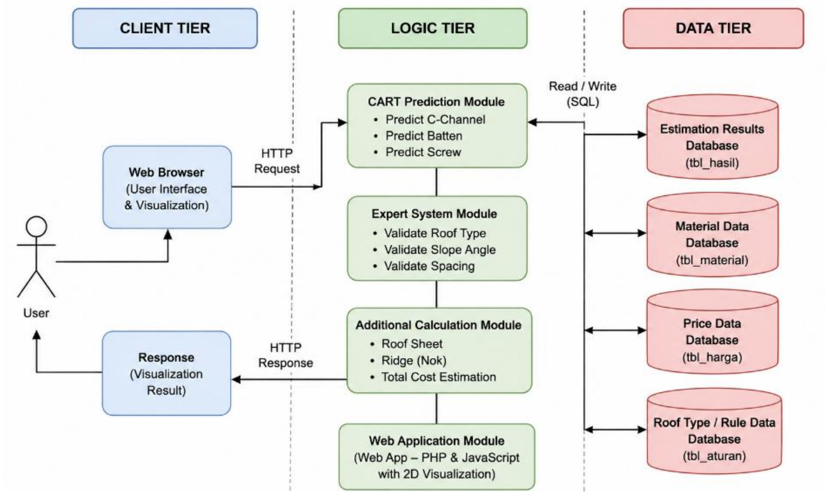


Figure 2. System Architecture of the Light Steel Roof Material Prediction System

As shown in Figure 2, the proposed system adopts a three-tier architecture consisting of the Client Tier, Logic Tier, and Data Tier. The Client Tier provides a web-based interface for users to input building dimensions, roof type, and roof pitch, while displaying material predictions, cost estimates, and 2D roof visualizations. The Logic Tier processes user inputs using the CART algorithm to predict the required quantities of C-channels, battens, and screws. The prediction results are then validated through a Forward Chaining expert system, followed by additional calculations for roofing sheets, ridge caps, and total cost estimation. The Data Tier stores the research dataset, material and pricing data, expert system rules, and prediction results.

2.2 Machine Learning Model Design (CART)

The machine learning model in this study was designed to automatically predict the primary material requirements for light steel roof construction based on building characteristics. The Classification and Regression Tree (CART) algorithm was selected because it generates simple, interpretable, and effective decision rules for classification tasks. The model predicts the quantities of the main roof frame materials, including C-channel steel, battens, and screws. The input variables consist of building length, building width, roof type, and roof pitch angle, as these factors directly influence the roof area, structural configuration, and material requirements. These inputs are processed by the CART algorithm to identify decision patterns for estimating the required materials.

During the training process, CART recursively partitions the dataset by selecting the optimal attribute at each decision node using the Gini Index criterion. The resulting decision tree consists of classification rules that enable the system to predict the required quantities of the main roofing materials accurately and efficiently based on the user's building specifications.

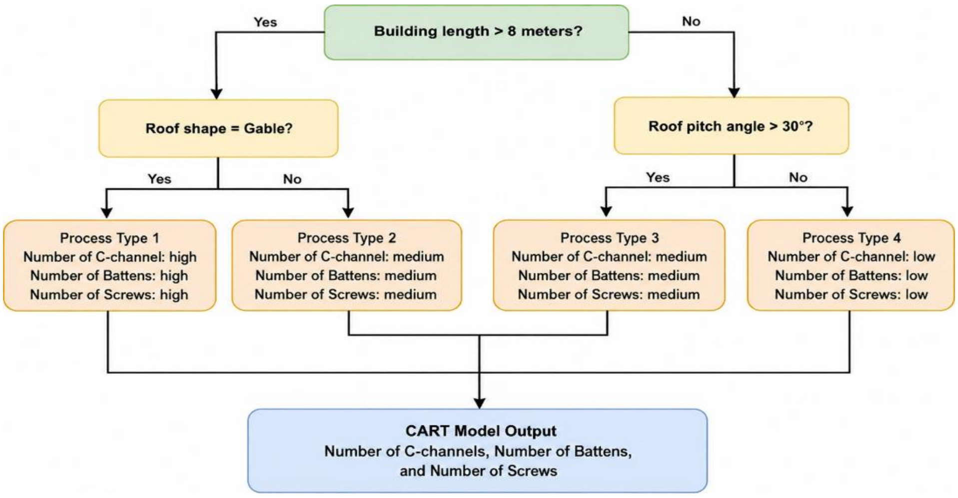


Figure 3. Decision Tree Structure of the CART Algorithm

As shown in Figure 3.4, the CART decision tree begins with the root node and recursively splits the data based on the most relevant attributes. Each branch represents a decision rule, while the leaf nodes provide predictions of the primary roofing materials, including C-channels, battens, and screws. Material quantities for roofing sheets, ridge caps, and total cost are calculated separately through the expert system and calculation modules. This integrated approach enables the system to automatically estimate material requirements accurately and efficiently based on the building specifications.

2.2 Dataset Preparation

The dataset used in this study consists of 100 simulated building scenarios (S001–S100) representing various light steel roof geometries and technical parameters. The input attributes include building length, building width, floor area, roof type, roof pitch angle, roof overhang, truss spacing, batten spacing, and roofing sheet length, while the output attribute is the material requirement category, representing the estimated quantities of C-channels, battens, and screws. To develop the prediction model, the dataset was divided into 80% training data (80 samples) and 20% testing data (20 samples). The training set was used to construct the CART decision tree, whereas the testing set was employed to evaluate the prediction performance of the developed model.

3. Results And Discussions

This section describes the data analysis process used to develop the light steel roof material prediction system. The analysis includes the identification of input and target variables, the division of the dataset into training and testing sets, and the construction of the CART decision tree using the Gini Index as the splitting criterion.

3.1 Research Dataset and Data Partitioning

The dataset consists of 100 simulated building scenarios (S001–S100) representing various light steel roof geometries and technical parameters. It includes input variables (building dimensions and roof specifications) and a target variable (material requirement category). The dataset was divided into 80 training samples (80%) and 20 testing samples (20%) to train and evaluate the CART model.

Table 1. Attributes of the Light Steel Roof Material Estimation Dataset

No.	Attribute	Variable Type	Unit / Format	Description
1	Input Mode	Input	Text	Input scenario selection (Simulation / Manual)
2	Building Length (L)	Input	Meter (m)	Length of the building floor plan
3	Building Width (W)	Input	Meter (m)	Width (span) of the building floor plan
4	Building Area	Input	Square Meter (m^2)	Floor area calculated as L × W
5	Roof Type	Input	Category	Roof shape (Gable, Hip, Pyramid, Lean-to)
6	Roof Pitch (θ)	Input	Degree (°)	Roof slope angle
7	Roof Overhang	Input	Centimeter (cm)	Length of the roof overhang beyond the wall
8	Truss Spacing	Input	Meter (m)	Distance between adjacent roof trusses (1.2 m)
9	Batten Spacing	Input	Centimeter (cm)	Distance between adjacent battens supporting the roofing sheets
10	Roofing Sheet Length (Spandek)	Input	Meter (m)	Effective length of the roofing sheet

The dataset was divided using an 80:20 ratio, comprising 80% training data and 20% testing data from a total of 100 simulated scenarios. The training set (80 samples, S001–S080) was used to construct the CART decision tree model by learning the underlying decision patterns. The testing set (20 samples, S081–S100) was then used to evaluate the prediction accuracy and overall performance of the developed model.

3.2 System Implementation

The system implementation translates the proposed architecture and system design into a web-based application. The application was developed using a Single Page Application (SPA) architecture, integrating PHP, MySQL, JavaScript, and HTML5 Canvas to support dynamic 2D roof visualization. A sidebar navigation provides access to the eight main modules of the system, enabling users to perform material prediction, cost estimation, and roof design visualization efficiently.

3.2.1 Home Interfac

The Home page serves as the landing page of the proposed system. It introduces the workflow of the application (Input Data → Estimate Materials → View Results → 2D Visualization), highlights the four main system features, and provides an overview of the key components of a light steel roof, including the ridge cap, roof overhang, truss, batten, C-channel, roof pitch, water flow direction, and roof span. This interface helps users understand the system and the basic roof structure before performing material estimation.

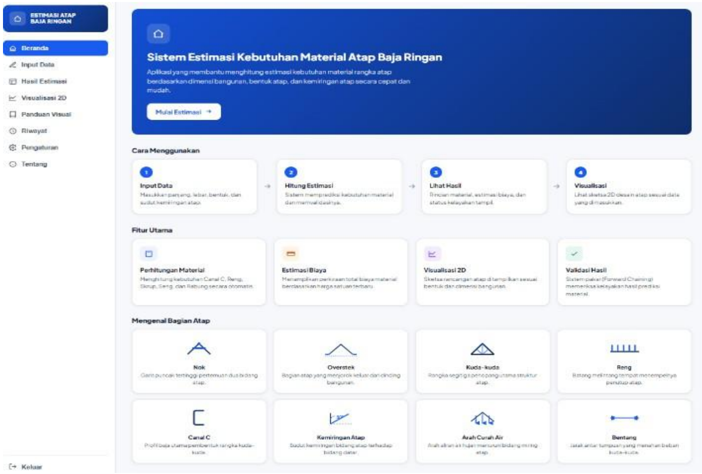
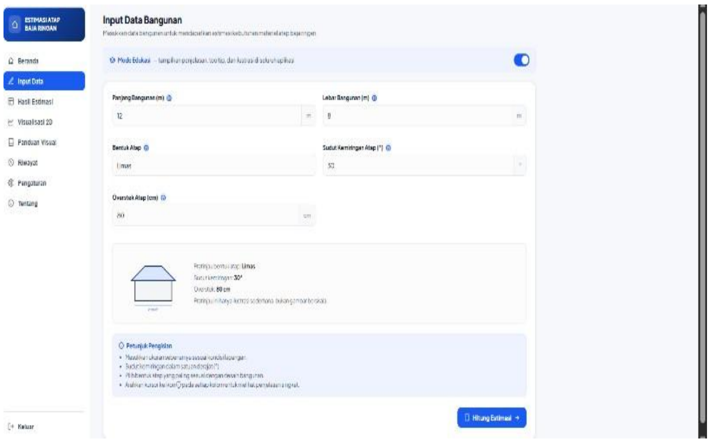


Figure 4. Home Interface and System Workflow

3.2.2 Building Data Input Interface

This page allows users to enter the building geometry and technical specifications required for material estimation. The interface includes an Education Mode that provides tooltips for each input field, a building parameter form for entering the building length, width, roof type, roof pitch, and roof overhang, and a real-time roof preview that displays a 2D roof sketch before the material estimation process is executed.



Gambar 5. Antarmuka Form Input Data Bangunan

3.2.3 Estimation Results and Expert Validation Interface

The Estimation Results page presents the output of the prediction process through four main sections. The Header Cards display the expert validation status (Valid or Requires Review), total estimated cost, roof area, and estimated installation time. The Building Data and Geometry Analysis section summarizes the input parameters and calculated values, including floor area, ridge length, roof surface area, and perimeter. The Structural Analysis section provides information on the number of trusses, truss spacing, steel profile, and roof span. Finally, the Material and Cost Estimation section lists the required quantities of C-channels, battens, screws, roofing sheets, and ridge caps, together with their specifications, quantities, unit prices, subtotals, and the overall estimated material cost.

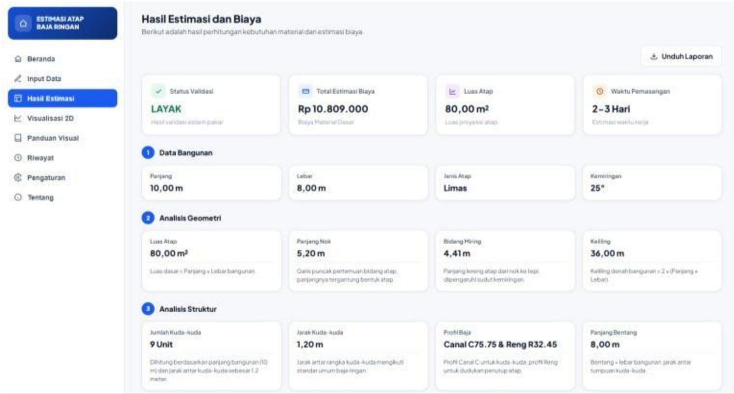


Figure 6. Estimation Results and Expert Validation Interface

3.3 System Validation and Testing

System validation and testing were conducted to evaluate the functionality, prediction accuracy, and technical feasibility of the proposed application. The evaluation aimed to ensure that the system operated according to the specified functional requirements, produced reliable material predictions, and complied with practical construction standards based on expert validation.

3.3.1 Functional Testing (Black-Box Testing)

Functional testing was conducted using the Black-Box Testing method, which evaluates the system by examining its input and output behavior without considering the internal program structure. The objective of this test was to verify that each system function operates correctly and produces the expected output according to the specified requirements. The functional testing results are presented in Table 2.

Table 2. Black-Box Testing Results

No.	Module / Feature Tested	Test Scenario	Expected Result	Status
1	Building Data Input Form	Enter the building length, width, roof type, and roof pitch through the user interface.	The system accepts numerical inputs and dropdown selections with appropriate input validation.	Passed
2	CART Prediction Module	Run the material estimation process based on the input building dimensions.	The system predicts the required quantities of C-Channels, Battens, and Screws using the CART decision tree model.	Passed
3	Forward Chaining Expert System Module	Enter extreme input conditions (e.g., roof pitch < 15° or lean-to roof span > 10 m).	The system displays the validation status "REQUIRES REVIEW" along with an appropriate technical warning message.	Passed
4	Additional Calculation Module	Calculate the sloped roof area to estimate roofing sheets and ridge caps.	The system calculates the required quantities of roofing sheets, ridge caps, and the total estimated material cost.	Passed
5	HTML5 Canvas 2D Visualization Module	Modify the building dimensions and switch between visualization tabs (Plan, Front, Side, Truss, and House).	The system dynamically renders a proportional 2D roof visualization on the HTML5 Canvas.	Passed

6	Report Download Feature	Click the download button on the estimation results page.	The system downloads the estimation report as a text document (.txt) or a visual image (.png).	Passed

3.3.2Expert Validation of the Rule-Based System

The technical feasibility, structural validity, and correctness of the expert system were evaluated by a light steel roof construction expert, Mr. Muhammad Muslim, S.T. The validation focused on assessing the Forward Chaining rule base and the material estimation logic to ensure consistency with practical construction standards. The signed evaluation form is provided in Appendix A, while photographs of the validation and interview sessions are included in Appendix B.

Table 3. Expert Validation Results of the Rule-Based System

No.	Technical and Construction Logic Evaluation Criteria	Expert Score (1–4)	Percentage (%)	Feasibility Category
1	Correctness of the Roof Pitch Safety Limits (15°–45°)	3.50	87.50%	Highly Feasible
2	Accuracy of Critical Roof Span Warnings and Structural Reinforcement	3.50	87.50%	Highly Feasible
3	Correctness of the Forward Chaining Inference Logic (Rule Base)	3.00	75.00%	Feasible
4	Accuracy of the Main Material Requirement Estimation (C-Channels, Battens, and Screws)	3.00	75.00%	Feasible
Average Overall Evaluation		3.25	81.25%	Feasible for Use

The expert evaluation produced an average score of 3.25 out of 4.00 (81.25%), indicating that the proposed system is feasible for practical use. The lower score assigned to the inference logic and material estimation reflects the use of a single-truss calculation model, which does not fully represent the structural complexity of hip and pyramid roofs. In practical construction, these roof types require additional structural components, such as half-trusses and jack trusses, which are not explicitly considered in the current rule base. Consequently, an additional material allowance is still required for these roof configurations. This limitation was identified as the primary factor influencing the expert evaluation and highlights an important area for future system improvement.

3.3 System Validation and Testing

System validation and testing were conducted to evaluate the functionality, prediction performance, and technical reliability of the proposed application. The evaluation aimed to ensure that the system operates according to the specified functional requirements, produces accurate material predictions, and complies with practical construction standards. The proposed system achieved a 95.0% prediction accuracy, demonstrating that the CART algorithm effectively estimates the material requirements for light steel roof construction based on building dimensions and roof specifications. The integration of the Forward Chaining expert system improves prediction reliability by validating the results against construction rules and providing warnings for unsuitable designs. Expert evaluation yielded a feasibility score of 81.25%, indicating that the system is suitable for practical use. However, the current model applies a simplified truss calculation, which may require an additional 5–8% material allowance for complex roof types such as hip and pyramid roofs. Furthermore, the 2D roof visualization enhances user understanding by presenting the estimated roof design graphically, making the system more useful for planning and communication between homeowners and construction practitioners.

Overall, the proposed system provides an accurate and efficient decision-support tool for material estimation.

4. Conclusion

This study successfully developed a web-based material requirement prediction system for light steel roof construction by integrating the Classification and Regression Tree (CART) algorithm, a Forward Chaining expert system, and HTML5 Canvas-based 2D visualization. The proposed system enables users to estimate material requirements, calculate construction costs, and visualize roof designs through an integrated platform. Experimental results show that the CART model achieved a prediction accuracy of 95.0% using 100 simulated building scenarios (80 training samples and 20 testing samples), demonstrating its effectiveness in predicting the quantities of primary roofing materials based on building dimensions and roof specifications. Furthermore, expert validation produced a feasibility score of 81.25%, indicating that the developed system is suitable for practical application. The integration of the Forward Chaining expert system enhances the reliability of prediction results by validating them against predefined construction rules, while the 2D visualization module improves users' understanding of the proposed roof design. Although the system provides accurate and efficient material estimation, future work should focus on improving the prediction model for more complex roof structures, such as hip and pyramid roofs, and validating the system using larger real-world construction datasets to further enhance its accuracy and practical applicability.

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