Multi-criteria Decision of Type and Building Material for Simple House Construction

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Abstract: Facing the innovation technology in building construction, the designer has the option in selecting the type of system construction and building materials. There is a big question for the designer and owner on how to evaluate the quality material to meet the technical requirements as building construction reliability. By demand to provide a low cost house, there is need for improving structure model and material construction for residents. When material cost takes 60%-70% of total construction cost, it is important to select the appropriate building material. Currently the innovation of material building for main frame and wall component has present for residential projects in Indonesia. Attempt to replace the traditional material such as brick or pozzolan lime concrete block is developed a new material include utilization of coal combustion waste for concrete block, lightweight concrete, or prefab panel wall. This paper presents the research result to develop a tool support for material and system construction selecting that facilitates the selection an optimal material for a simple house construction. A multi-criteria decision method is used based on performance criteria such as economy, reliability, comfort and eco-friend.

Key words: Multi-criteria decision, building material, simple house.

1. Introduction

Problem in housing development for low income people in the developing countries, such as in Indonesia, it is complex and complicated that involve many sectors related such as land, finance, institution, technology and others. According to the performance record of the house development in 2010, about 150,000 new plan units recovered 62% only due to many constraints such as in technical issue and building materials. This challenge requires an innovation to get technology construction that “efficient and reduce costs” but still has proper technical quality and “empowering labour” [1]. RIHS (Research Institute for Human Settlement), Ministry of Public Works have done much reseach to innovate a construction system and utilization of local building materials for simple houses. Some innovations have been produced for instance reuse the coal combustion waste as material additive for wall panel component or

hollow conblock, reuse wood waste for comblock component, bamboo mat plastered for wall panel, utilization prefabrication components for the main frame house. Refer to the laboratory test indicated result those components have sufficient technical requirements which then can be appllied for simple house constructions. However, for futher application, such as utilization in mass production, more futher study is still needed.

Every party, who involved to the house project, may have a different characteristic (which called attribute) when deciding an important one. For the investors, the decision is often evaluated a new construction product using traditional economic measures such as life cycle cost, rate of return or payback [2]. For the architects prefer to choose attribute of attractiveness of design inside and outside of house construction or for the structural engineers decide based on structural servicebility, while the residents choose a house based on accessibility to commuter station and comfortability is more important. However, the best for houses depends on what you mean by “best”. Does “best”

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mean strongest stiffness, “cheapest” mean most readily available or most attractive, or all of these or non of the best [3]. The decision needs a method that accounts for attributes when choosing among building alternatives.

Concern in the simple house construction, selecting process for system construction and building material is crucial step that will influence construction cost significantly. If the house construction was evaluated as the single building physically, the procurement cost for building material needs 60%-70% approximately of the total building cost [4]. For the conventional house construction, the building material cost is dominated for reinforced concrete frame 29%, bricks masonry 9.2%, for roof covering tile clay 17%, and the rest for other materials. Therefore the innovation for simple house construction will be focused to explore alternative building materials for those components. Yet innovation may reduce the construction cost only, it is not yet deserved as the best alternative.

The main objective of this paper is to develop a multicriteria decision analysis framework to evaluate the technical performance of building construction considering various combination system main frame and components materials. This paper presents an overview for making decision where non financial consideration is important. The scope study is limited to residential construction which was constructed by RIHS as the project research in budget year 2010 and the project construction located in Turangga area, Bandung. The options consist of seven house types by the same design plan for each. Five houses apply the masonry wall, which is common material for residential in Indonesia. The rest ones are applying wall panel components.

2. System and Material Construction Selection

At early step of a house planning, the designers often must decide a type construction and building material based on several technical requirements. The first decision to be made is whether the structure will be

framed or un-framed. In a framed structure, the frame components for a simple house are usually of reinforced concrete or timber. The house will also have external and internal walls, but these components are non-structural components and support no load except than their own weight. Therefore, beside a technical requirement based on the laboratory test result, the historical record based on past performance and user satisfaction observation is also important to consider. Nevertheless, it is not easy to collect the users' feedback data. When an innovation of building materials is gained, the technical record often based on laboratory test result only without full scale implementation research [4].

Due to technology, daily living pattern has changed. New building systems and construction techniques to solve present space need have to be developed. Engineering and design need to be directed toward making construction method more efficiently and economically. Complexity in facility requirements also makes it imperative that design professionals develop better methods of indentifying user needs so that more effective design solutions can emerge. The complexity of these change requires that they dealt with systematically in the decision-making process [5]. Major constraints such as material availability and cost requirement that design prefossionals work comperatively with clients and consultants to clarify needs, priorities and design options. To perform a multi attribute in decision-making analysis, Table 1 differently presents the alphabetical list of attributes to help in indentifying the typical building decision. 15 attributes refer to building-related factors, 10 attributes refer to material selection, and nine attributtes refer to performance requirement. There is no one building material that is the best in all respects. If there were, then every building structure in the entire world would be built out of that one material [3]. It is apparent that there are many different materials that can be used in building, each of which has its advantages and disadvantages.

Table 1 Factors to be considered in the type construction and material selection [2, 3, 6].

Building-related selection			Material selection		Perfomance requirement
1	Aesthetics	1	Mobility	1	Code acceptability
2	Building functions	2	Availability	2	Compatibility
3	Durability	3	Cost/economics	3	Economic
4	Economics	4	Durability	4	Fire safety
5	Environmental impacts	5	Disposal	5	Durability
6	Flexibility in functionnal	6	Fire protection	6	Habitability
7	Information technology	7	Size and nature of the site	7	Maintainability
8	Location	8	Speed of erection	8	Practicability
9	Occupancy availability	9	Stiffness	9	Serviceability
10	Operation and maintenance	10	Strength		
11	Reliability				
12	Security				
13	Sound and visual environment				
14	Thermal and air quality				
15	Transportation				

Determining the attributes will use to decide the criteria. Because the house project has the same location and function, those attributes need to eliminate. The decision just considers the attribute of economic issue, strength and environment impact. The details of the attributes are described as following:

(1) Building cost: The cost of a unit house covers from foundation up to roof covering and their facilities such as for sanitation and electricity. This approach to reduce the price of materials applied to the building will be the best;

(2) Construction time: The duration of constructing the building is availability for the labors;

(3) Sound isolation: The privacy of conversations, level of ambients noise the designers are controlling over this condition;

(4) Thermal conductivity: The rate of heat flow varies with different materials and depends on its thermal conductivity (k). The lower the conductivity is, the better the material of an insulator is;

(5) Strength: The materials must be strong enough and resist the pressure to a certain load.

3. Method and Case Study

Method of multi-criteria analysis is study of indentifying and choosing alternatives based on the

values and preferences of the decision maker. There are four steps in the process to analyse the decision:

- (1) problem definition;
- (2) requirement identification;
- (3) goal establishment;
- (4) evaluation criteria development.

The process flows from (1) to (2), but may return to a previous step from any points in the process when new information is discovered [6]. In this study, the problem definition will evaluate technical performance of residential construction which is constructed by various material type for their envelope structure. If goals are clearly identified, the designer will be able to develop steps in a process for selecting building material to satisfy users' requirements.

3.1 Identified Methodology

For the evaluation such as the SAW (simple additive weighting) method and WPM (weight product method) or other known as MEW (multiplicative exponential weighting), the model is to aggregate the scores into one score based on the criteria weight [7].

The SAW method can be described as follow:

- (1) Selecting the set of the most important criteria x_j , describing the feasible alternatives;
- (2) Constructing the decision-making matrix X using

Eq. (1):

$$X = \begin{bmatrix} x_{11} & x_{21} & \cdots & x_{1j} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{in} \end{bmatrix}; i = \overline{1, m}; j = \overline{1, n} \quad (1)$$

where, m is the number of alternatives; n is the number criteria; x_{ij} is value of j criteria in alternative i ;

(3) The normalized $\overline{x_{ij}}$ values of the j criterion for i alternatives are calculated as Eqs. (2) and (3):

$$\overline{x_{ij}} = \frac{x_{ij}}{\max(x_{ij})}, \text{ if preference is maximum} \quad (2)$$

$$\overline{x_{ij}} = \frac{\min(x_{ij})}{x_{ij}}, \text{ if preference is minimum} \quad (3)$$

(4) The optimality criterion L_i of alternatives equals to the sum of the weighted criteria values. Use Eq. (4):

$$L_i = \sum_{j=1}^n (\overline{x_{ij}} w_j) \quad (4)$$

where, w_j is the weight of j criterion.

The weight product method is quite similar to the SAW. However, instead of calculating “sub-scores” by multiplying performance scores times attribute importances, the weight becomes exponents associated with each attribute value. Positive power is for benefit attribute and negative power for cost attribute. The optimality criterion V_i of alternatives uses Eq. (5):

$$V_i = \prod_{j=1}^n (x_j^{w_j})_i \quad (5)$$

The SAW and WPM methods need criteria weights. Weight of the criteria is determined by applying the AHP (analytic hierarchy process) method. Table 2 provides pair-wise comparison matrix. Essence of the AHP method is to construct a matrix expressing the relative value of a set of criteria. A relative scale is used to compare two objects at a time [8]. The value of λ_{max} is for eigenvalue maximum, CI is for consistency index and CR is for consistency ratio. If CR is less than 10%, it indicates sufficient consistency.

3.2 Case Study

Seven different houses were selected as the alternatives (A_1 up to A_7). They have approximate same design plan, each unit has a total building areas 36 m^2 and stands on 90 m^2 parcel of land. Five houses are built by masonry wall. Four of those were framed by conventional RC (reinforced concrete) and another was framed by precast concrete. Two houses are built by panel wall. One was framed by lightweight concrete material and the other was framed by timber. Those alternatives were located at the same area, Turangga, Bandung and were built in the end of 2010. The details of the alternatives are shown in Table 3.

4. Result and Discussion

A thorough analysis of the initial values of possible alternatives could evidently show that there are no alternatives which are the best or the worst according to it. The decision-making matrix was compiled according to Tables 3 and 4. Table 5 shows the initial decision matrix of the problem. All the meaning of criteria and alternative refer to Tables 3 and 4. The normalized values are determined according to Eqs. (2) and (3) and are presented in Table 5. Weighted-normalized value of the criteria are presented in Table 6 for SAW method and Table 7 for WPM method. The resume results of all the methods are represented in Table 8. Although the purpose preferred to get the cheap material cost, the best performance of a house construction must be based on several technical criteria. For this case study, the house by framed prefabricated concrete and brick wall is best by its performance.

5. Conclusions

The study evaluates seven simple houses based on multiple criteria of economically, realibility and comfortability. There is determined set of criteria for problem solution and present multi-criteria problem solution model. Although economic aspect is most

Table 2 Pair-wise comparison matrix.

	C ₁	C ₂	C ₃	C ₄	C ₅
C ₁		3	7	5	2
C ₂	$\frac{1}{3}$		3	2	$\frac{1}{7}$
C ₃	$\frac{1}{7}$	$\frac{1}{3}$		$\frac{1}{3}$	$\frac{1}{5}$
C ₄	$\frac{1}{5}$	$\frac{1}{2}$	3		$\frac{1}{3}$
C ₅	$\frac{1}{2}$	7	5	3	
Weight	W_1 0.410	W_2 0.114	W_3 0.045	W_4 0.089	W_5 0.343
λ_{max}	5.357832				
CI	0.089458				
CR	8%				

Table 3 System construction and building material used for each alternatives house.

Name alternatives	Main frame	Wall	Foundation	Roof	Plafond
A ₁ Conblok	RC in site	Pozzolan-lime block solid ^a			
A ₂ Brick	RC in site	Red bricks ^a			
A ₃ Aecon	RC in site	Aerated concrete	All alternative use stone masonry	All alternative use timber structure and clay tile for covering	All alternative use gypsum sheet
A ₄ Copanel	RC in site	Fly + bottom ash panel ^b			
A ₅ Coalcon	Lightweight RC	Fly + bottom ash conblock ^c			
A ₆ Bampam	Laminated veneer lumber	Bamboo mat plastered panel ^d			
A ₇ Prefab	Prefab RC	Red bricks			

^a Brick/conblock units from Garut, West Jawa, mortar 10 mm thickness use proportion 1 (cement):5 (sand);

^b Mix material proportion 1 cement: agregate, which agregate 60% sand:20% fly ash:20 bottom ash;

^c Mix material for conblock use 1 cement:3 agregate (60% sand:20% fly ash:20 bottom ash), mortar 1:5;

^d Bamboo mat 20 mm thickness set interval gap 50 mm × 50 mm net, and mortar plaster 1:5.

Table 4 Initial matrix of the problem description [9-11].

Criteria	C ₁	C ₂	C ₃	C ₄	C ₅
	Building cost	Construction time	Sound insulation ^a	Thermal conductivity ^a	Compression strength ^a
Dimension	Million (Indonesia rupiah)	Days	SRI ^b	W/m·K	N/mm ²
Opt direction	min	min	max	max	max
Weight	0.410	0.114	0.045	0.089	0.343
A ₁ Conblo	81.42	59	50	0.71	2.50 ^c
A ₂ Brick	82.37	62	45	0.61	5.09 ^c
A ₃ Aecon	87.37	55	42	0.46	2.50 ^c
A ₄ Copanel	79.45	40	43	1.18	5.00
A ₅ Coalcon	81.39	62	47	1.02	3.02 ^c
A ₆ Bampa	72.15	65	25	1.70 ^d	2.68 ^e
A ₇ Prefab	80.27	50	45	0.61	5.09

^a Refer to wall materials test result;

^b SRI: sound reduction index;

^c Base on the average of the compression test per unit;

^d By assumption thermal conductivity for cement mortar approximate;

^e Flexure strength.

Table 5 Normalized decision making matrix.

Alternatives	Criteria				
	C ₁	C ₂	C ₃	C ₄	C ₅
A ₁	0.886	0.678	1.000	0.648	0.828
A ₂	0.876	0.645	0.900	0.754	1.685
A ₃	0.826	0.727	0.840	1.000	0.828
A ₄	0.908	1.000	0.860	0.390	1.656
A ₅	0.886	0.645	0.940	0.451	1.000
A ₆	1.000	0.615	0.500	0.271	0.887
A ₇	0.899	0.800	0.900	0.754	1.685

Table 6 Weighted-normalized decision making matrix for SAW method.

	C ₁	C ₂	C ₃	C ₄	C ₅	L _i
A ₁	0.3630	0.0774	0.0447	0.0576	0.2837	0.8263
A ₂	0.3588	0.0736	0.0402	0.0670	0.5777	1.1173
A ₃	0.3382	0.0830	0.0375	0.0889	0.2837	0.8314
A ₄	0.3720	0.1141	0.0384	0.0346	0.5674	1.1266
A ₅	0.3631	0.0736	0.0420	0.0401	0.3427	0.8615
A ₆	0.4096	0.0702	0.0223	0.0240	0.3042	0.8304
A ₇	0.3682	0.0913	0.0402	0.0670	0.5777	1.1443

Table 7 Weighted-normalized decision making matrix for WPM or MEW method.

	C ₁	C ₂	C ₃	C ₄	C ₅	V _i
A ₁	0.9517	0.9566	1.0000	0.9622	0.9373	0.82103
A ₂	0.9472	0.9512	0.9953	0.9752	1.1959	1.04588
A ₃	0.9246	0.9643	0.9922	1.0000	0.9373	0.82920
A ₄	0.9613	1.0000	0.9933	0.9197	1.1886	1.04380
A ₅	0.9518	0.9512	0.9972	0.9317	1.0000	0.84122
A ₆	1.0000	0.9461	0.9695	0.8903	0.9599	0.78390
A ₇	0.9573	0.9749	0.9953	0.9752	1.1959	1.08327

Table 8 The solution ranking matrix.

Name alternatives		SAW method	WPM or MEW method
A ₁	Conblo	7	6
A ₂	Brick	3	2
A ₃	Aecon	5	5
A ₄	Copanel	2	3
A ₅	Coalcon	4	4
A ₆	Bampa	6	7
A ₇	Prefab	1	1

important for selecting the type and material construction for simple house, non financial aspects must be determined as well. The result analysis shows that the last house type, which is a house framed by

prefabrication reinforced concrete material and bricks masonry for wall camponents, is the best performance taking into account building cost, construction time, sound insulation, thermal conductivity and

compression strength aspects. There are two different results for the worst performance which are evaluated by the simple additive weighting and the traditional conblock masonry wall as the worst, but by the weight product method indicate bamboo mat plastered wall panel.

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