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INTEGRATED AHP - VALUE ENGINEERING DECISION MAKING MODEL

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Abstract: Value Engineering (VE) is the most reputable practice that is being used during the early phases of project development and planning to enhance the project value. VE is producing numerous alternatives for a project based on predetermined criteria to select the optimum or near optimum alternative, which best addresses the functions. Therefore, the ability to make smart decisions is very important to the accomplishment of projects. This problem may become a very challenging one when different units measure the criteria or the pertinent data are difficult to be computed. Analytical Hierarchy Process (AHP) is an effective algorithm in dealing with this kind of decision complications. This paper provides VE decision-making model to choose optimum alternative based on the assessment of several alternatives in terms of a number of criteria through applying AHP. AHP algorithm was automated through using excel spreadsheet application to assess both criteria and alternatives. The developed model had been verified through applying it to real case study project. The project is Joubal lagoon resort that is located at El Gouna, Red Sea, Egypt. The architectural block façade system was the selected item for VE study. The selected criteria for the VE study were eight criteria and VE team had defined three alternatives. The developed model, methods and algorithms augment VE application and expand upon alternatives and criteria evaluation.

1 Introduction

The construction industry has changed over the previous decades. Buildings have become much more complex with many interrelated and integrated systems. This complication has forced the engineers in the Architecture/Engineering/Construction (AEC) industry to study more inputs in their design analysis. With the added difficulties, architects, owners, and contractors had to adapt to these changes and take in considerations more factors than before in order to keep up with the continuously growing industry (Davis, 2004). To scrutinize these factors in a proper manner where all communication requirements are met, designers are searching for better ways to coordinate all this information together throughout all the parties' involved (Dell Isola., 2013). Value Engineering (VE) is a planned effort to analyze the functions of systems, equipment, facilities, services and suppliers to attain the crucial function at the lowest life cycle cost with the essential quality, performance, reliability, and safety (Manosur and Hulshizer, 1997 and Younker, 2003).

VE provides organizations with a definitive tool to enhance the value of product, project or process. This technique has been used by manufacturers, design/construction contractors and other stakeholders (Rains, 1999 and Raj, 2002). Therefore, it is integrated early and seamlessly into the design process by the most experienced advisors who will provide valuable ideas to generate large cost savings and functional improvements (Garrido, 2013). VE can be applied wherever cost and/or performance improvement is required. That improvement can be measured in terms of monetary aspects and/or other critical factors (Fong, 1998 and Neidecker, 2010). A key to the successful application of a value study is the skills and experience of those applying the methodology. The team leader performs a key role and is a significant factor in the study degree of success. The team leader must have thorough training in both the VE and team facilitation. Since VE aims to complete the total function for lowest overall cost, it is essential to provide measures of the value of the function (Shen and Liu, 2003). One technique of assessment of the function is by comparison. A valid comparison should be done to establish the values. These values are then used as a guide to the achievement of the individual function or groups of functions for that value or cost (Miles, 1972 and Mao, 2008). Value study generally encompasses three stages which are Pre-Workshop (Preparation), Workshop (Execution of the six phases Job Plan) and Post-Workshop (Documentation and Implementation) (SAVE, 2007 and CSVE, 2016).

Multi-Criteria Decision Analysis (MCDA) is based on computational approaches used to support the subjective assessment of a finite number of options under a finite number of performance criteria, by a single decision maker or by a group of decision makers (El-Misalami, et al, 2006). Since its introduction by Professor Thomas Saaty in 1977, AHP has been applied widely in various research fields. The main concept was based mainly on the pairwise comparison matrices that decision maker uses to determine preferences between alternatives for different criteria and the rating methods (Saaty, 1980 and Saaty, 1994). This method is a popular alternative for deriving the preference structure in various practical applications of MCDM. The major strengths this method brings are its systematic procedure and its ability to examine the consistency of the evaluator's judgments. Technique that allows the consideration of both objective and subjective factors in selecting the best alternatives. This approach is used to arrive at a cardinal ranking of alternatives for multi attribute decision problems (Saaty, 2008). AHP has been a tool at the hands of decision makers and researchers; and it is one of the most widely used multiple criteria decision making tools. Many outstanding works have been published based on AHP: they include applications of AHP in different fields such as planning, selecting best alternative, resource allocations, resolving conflict, optimization, etc., and numerical extensions of AHP. AHP has been extensively utilized in several fields of the AEC industry such as contractor selection (Fong and Choi, 2000), procurement (Al-Khalil, 2002), maintenance (Shen et al., 1998), project management (Al-Harbi, 2001), Risk Factors (Baha et al., 2013), supply chain decisions (Cooper, 2012) and facility management (Gilleard and Wong, 2004).

The main objective of this paper is to integrate VE and AHP to enable decision makers to select the best alternative that satisfy client requirements. The model facilitates the process of criteria prioritization and alternatives evaluation process through AHP algorithm based on VE team members' assessment. The developed model ranks alternatives based on the calculated scores for each based criteria weights based on user's pairwise comparison.

2 Proposed Methodology

Figure 1 depicts a flow chart for the proposed methodology. First step is to conduct a pre study activities to get a clear understanding of what senior management needs to be addressed, what the strategic priorities are, and how improvement will increase organizational value plan and to organize the value study and the strategic priorities. Data collection starts by studying the status of the project and the constraints that affect project decisions. This phase brings all team members to a basic level of understanding of the project. Information phase is the next step to determine the needs, requirements, function and constraints of the owners/users/stakeholders, as well as the proposed criteria. Despite the existence of some prerequisite criteria for each building type, these criteria are not the same for every project. The criteria vary from owner to owner and from project to project. This fact proofs the reason that there is not a universal answer in the selection of an alternative for a project. To define criteria function analysis is conducted to focus on essential function. The functional understanding establishes the base case to identify and benchmark alternatives and mismatches and set the agenda for innovation. After finalizing the information phase, the project should be understood from a functional perspective; what must the project do, rather than how the project is currently conceived. The value study team is a multidisciplinary group of experienced professionals and project stakeholders. Team members are chosen based on their expertise and experience with the project. Team members define criteria based on the function analysis and the owner predefined criteria which are the first input. Pairwise comparison is conducted to apply AHP algorithm to get criteria the weights and Consistency Ratio (CR).

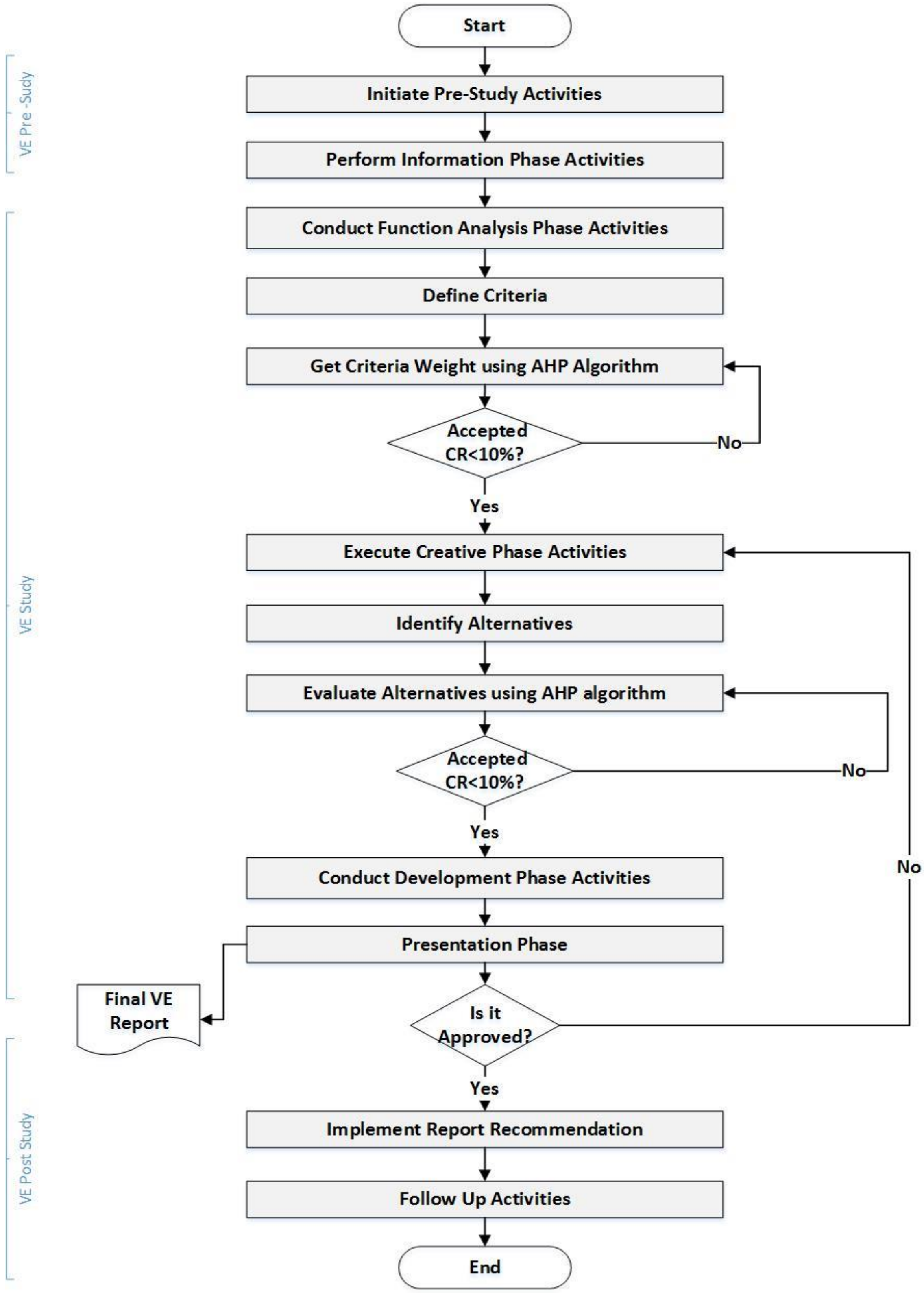

Figure 1- Proposed methodology

The AHP measures the consistency or inconsistency using the Consistency Ratio (CR), which is a function of comparison matrix dimension (n*n), a Random Index (RI), and the dominant eigenvalue λmax. Consistency Ratios (CR) are computed to measure the consistency of judgments. The use of the AHP basically serves 2 purposes: assigning weights to a set of predetermined criteria or measures; and prioritizing or ranking elements to identify the key elements. The "priority vector" (i.e. the normalized weight) is calculated for each criterion using the geometric mean of each row in the matrix divided by the sum of the geometric means of all the criteria followed by normalizing the resulting numbers. This process is then repeated for the alternatives comparing them one to another to determine their relative value/importance for each criterion. Empirical studies conducted by Saaty have indicated that a deviation in consistency ratio of less than 10% is acceptable without adversely affecting the results. In the function analysis phase, a pairwise comparison was done by users for each criterion to build the comparison matrix. CR value should less than 10% results to approve results otherwise, users should review the pairwise comparison to get final criteria weights and allow the model to develop criteria report as shown in Figure 2 and equations (Eq1 to Eq 8). Based on CR value, results should be approved or rejected, if it is more than 10% user should review pairwise comparison and correct the inconsistency on the data inputs. Creative phase is conducted after approving the criteria results to define various alternatives of achieving the same functions.

[1] Comparison Matrix $A=\begin{bmatrix} \boldsymbol{a11} & \boldsymbol{a12} & \dots & \boldsymbol{a1m} \\ \boldsymbol{1/a12} & \boldsymbol{a22} & \dots & \boldsymbol{a2m} \\ \dots & \dots & \dots & \dots \\ \boldsymbol{1/a1m} & \boldsymbol{1/a2m} & \dots & \boldsymbol{amm} \end{bmatrix}$

[2] Normalized Matrix $A_{norm}=\begin{bmatrix} A11 & A12 & \dots & A1m \\ A21 & A22 & \dots & A2m \\ \dots & \dots & \dots & \dots \\ Am1 & Am2 & \dots & Amm \end{bmatrix}$

[3] $A_{11}=a_{11}/ (a_{11}+a_{21}+am_1)$

[4] Eigenvector Matrix $W_{m*1}=\begin{bmatrix} W1 \\ W2 \\ W. \\ Wm \end{bmatrix}=\begin{bmatrix} (A11+A12+\cdots+A1m)/m \\ (A21+A22+\cdots+Am)/m \\ (\dots+\cdots+\cdots+\cdots)/m \\ (An1+An2+\cdots+Amm)/m \end{bmatrix}$

[5] Transition Matrix $AW_{3*1}=\begin{bmatrix} W1 \\ W2 \\ W. \\ Wm \end{bmatrix}\begin{bmatrix} A11 & A12 & . & A1m \\ A21 & A22 & . & A2m \\ . & . & . & . \\ Am1 & Anm & . & Amm \end{bmatrix}$

[6] $\lambda max = (1/m) \sum (awi / wi)$

[7] $(CI) = (\lambda max - m) / (m-1)$

[8] $(CR) = CI / R$

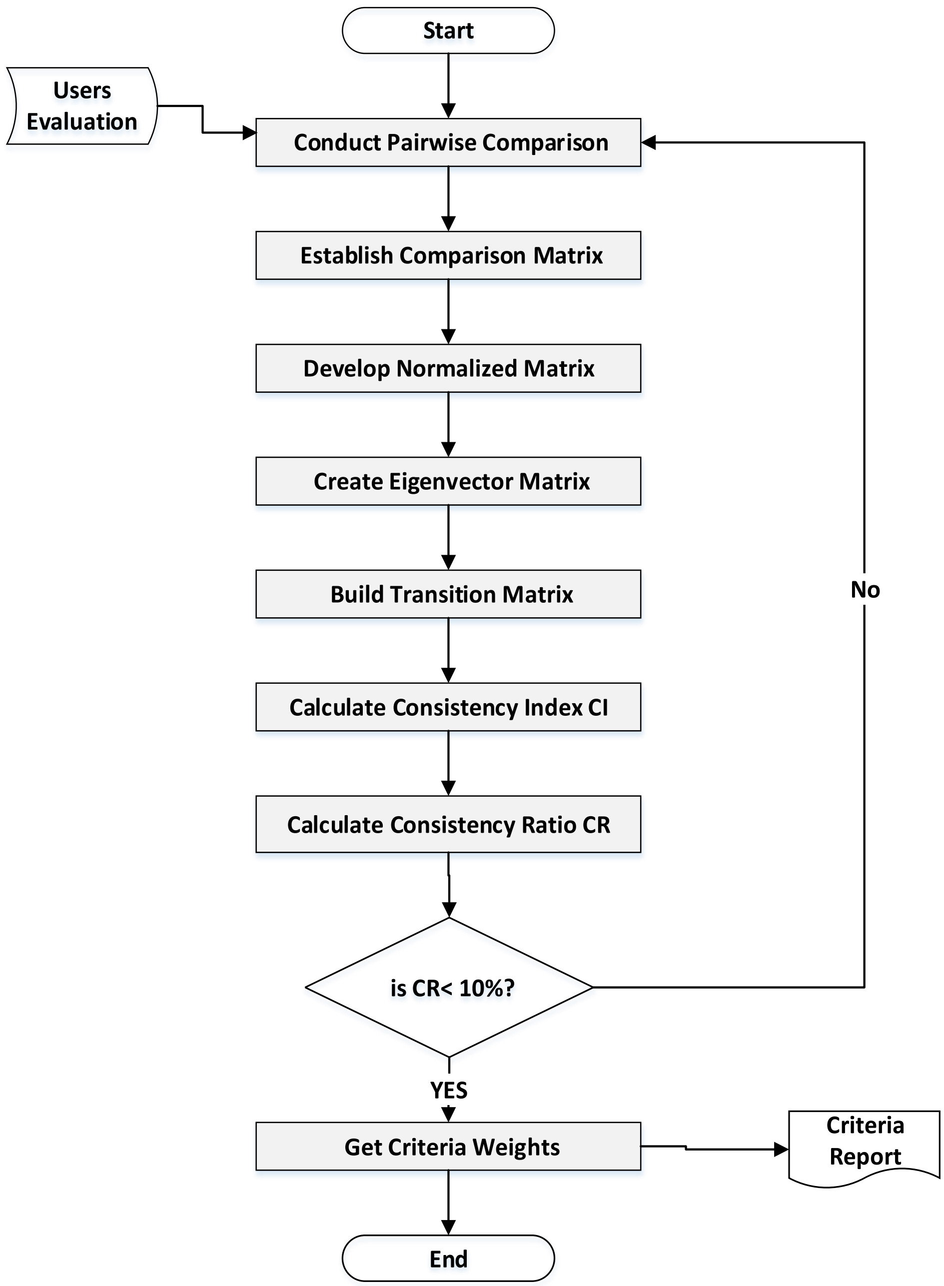

Figure 2- Criteria Evaluation Process

In this step VE team tries to generate several alternatives and ideas with focus on the pre-defined criteria. The alternatives should be generated in a way that improve value to the client and satisfy the clients' criteria while guarantee maximum value. In addition to special knowledge, sufficient tools and techniques are also needed so as to generate creative alternatives. On this stage users define alternatives and establish alternative-criteria pairwise comparison to get the score of alternatives. For each alternative-criteria comparison, comparison matrix, normalized matrix, eigenvector matrix, transition matrix and CR are calculated to assure inputs consistency in each comparison typically the same as criteria comparison process. Final criteria score is be calculated by summing the result of multiplying criteria weight and alternative weight on that criteria as shown in Eq 9. Alternatives' CR is also calculated as before to accept or reject the pairwise comparison and to move to next steps which are development and presentation phases, as shown in Figure 3.

[9] Alternative score = ∑ Criteria weight * Alternative score on that criteria

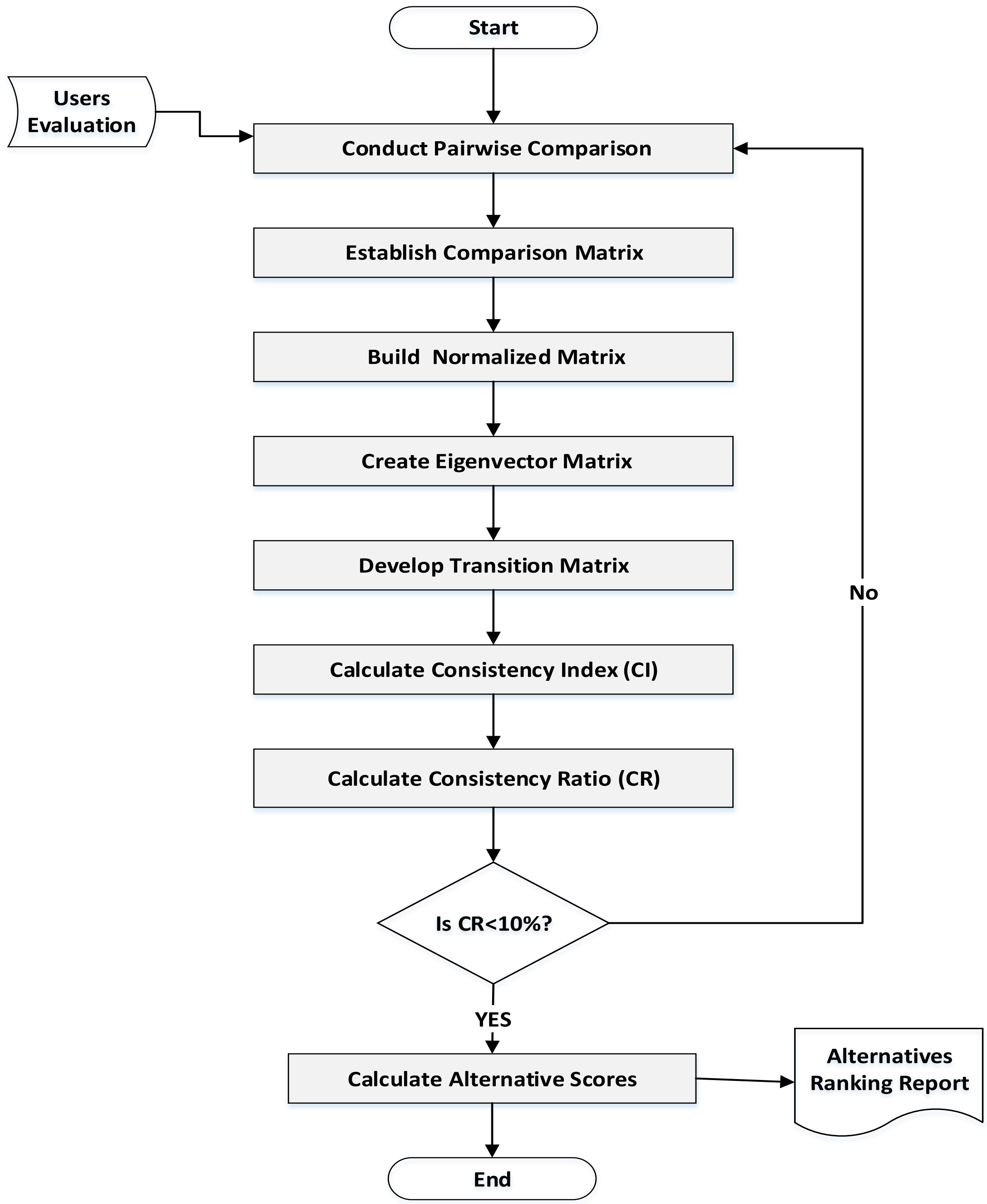

Figure 3- Alternative Evaluation Process

Final VE report is presented to get it approved by the client. Implementation and follow up activities are essential after approval of VE report. All the equations, algorithms and reports had been implemented in Microsoft Excel spreadsheet to facilitate the calculation and reporting process.

3 Model Verification

The proposed methodology had been applied to real project, which is Joubal lagoon located at El Gouna, Red Sea, Egypt. The project was developed by Orascom Development and it is a series of contemporary apartment blocks surrounded by a modern oasis of pools, water features, lush green landscape, and crisscrossed pathways. Inspired by pure geometric shapes used in Islamic architecture, the concept behind the architectural design of the apartment blocks is based on the manipulation of the basic geometric cube. Joubal pays homage to nature by incorporating energy efficient yet iconic features throughout the home, which help minimize the impact on the environment and by integrating nature and water into building materials. The project consists of 50 unit with 60,000 m2 built up area budget cost is 600 Million Egyptian Pounds (EGP). Location and perspective of the project are shown in figure 4. A typical building consists of 3 stories apartments with span ranging from 3.0 to 4.0 m and floor height around 3.0 m. The value engineering study was done for the architectural block façade system of the building. The final selected criteria for the case study are eight criteria, which are cost, time, appearance, serviceability to services and utilities requirements, material availability, durability, fire resistance and flexibility for future modifications. Criteria weights are calculated based on the VE team input. Table 1 shows the resulted weight and the CR, which is accepted. All results had been verified manually to ensure the correct AHP formulas are used. Cost was ranked as the most important criteria with 28.39% then time with 23.09%.

Figure 4- Project location and perspective

Table 1- Criteria Evaluation Report

Criteria	Ranking	Weight %
Cost	1	28.39%
Time	2	23.09%
Appearance	3	15.59%
Serviceability to services and utilities requirement	4	9.55%
Material availability	5	7.69%
Durability	6	6.11%
Fire resistance	7	5.61%
Flexibility for modifications	8	3.98%

After defining the criteria and final weights, the team members had defined 3 alternatives for the architectural block façade system. The first alternative was composed of external façade which are made of 25cm ordinary red clay bricks and 12 cm ordinary red clay bricks as internal partitions. Second alternative external façade and internal partitions are made of solid Concrete Masonry Units (CMU) 25 cm, while the third alternative external façade and internal partitions are made of light weight sand units 25 cm. Figure 5 presents the alternative-criteria hierarchy structure of the case study. To evaluate the alternative more objectively, a 3D BIM model was developed to calculate the quantities more accurately and to support the VE team in assessing the aesthetic criteria. Figure 6 presents the developed 3D BIM model that was used also in calculating cost and time of each alternative.

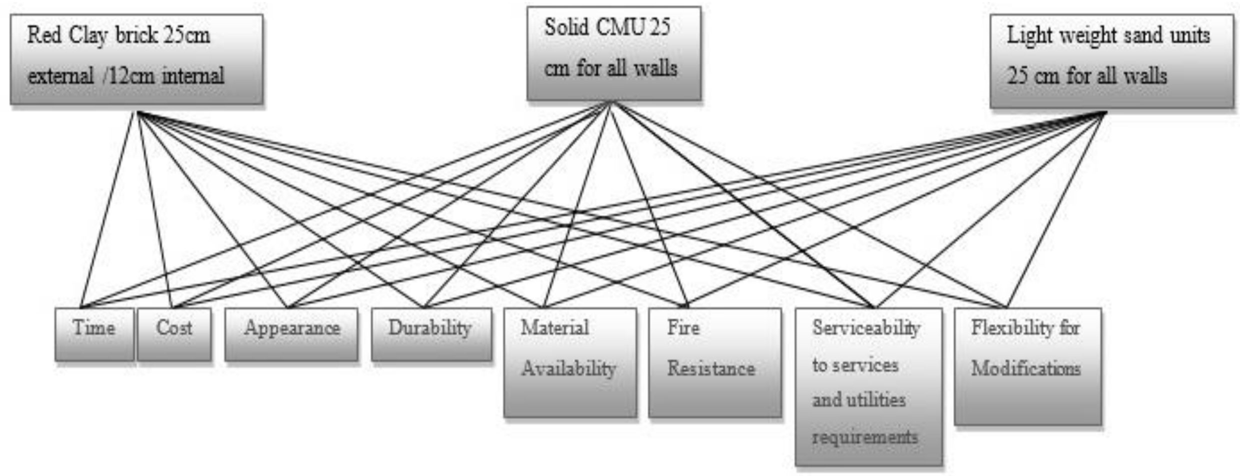

Figure 5- AHP Hierarchical Structure

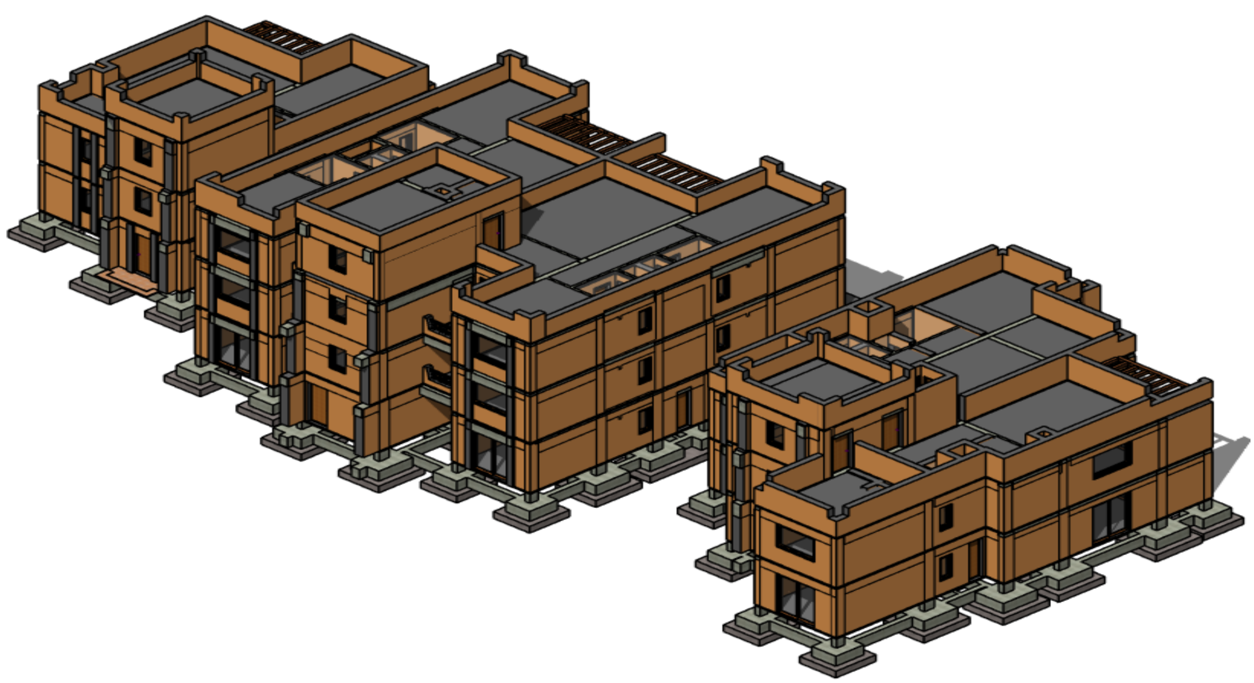

Figure 6- 3D BIM model used for evaluation

Pairwise comparison had been conducted for each criteria between alternatives. Cost and time had been estimated by VE team to assess alternatives for those criteria. The results were CMU cost equals to 1,951,947 EGP and 143 day construction duration, while the sand units cost is 2,212,107 EGP and 133 day construction duration. The red clay cost equals to 1,679,484 EGP and 128 day construction duration. Table 2 and 3 are showing sample of alternative-criteria comparison results for the 3 alternatives, which had been used to get the overall score and ranking of the alternatives. After assessing all alternatives red clay had been ranked first as the best alternative for Joubal with score 33.79% as shown in figure 8.

Table 2- Alternatives-Fire Resistance Comparison

Alternative-Fire Resistance	Ranking	Weight %	CR
Sand Unit	1	38.39%	
CMU	2	33.09%	5%
Red Clay	3	28.05%	

Table 3- Alternatives-Cost Comparison

Alternative-Cost	Ranking	Weight %	CR
Red Clay	1	38.13%	
CMU	2	32.82%	0%
Sand Unit	3	28.99%	

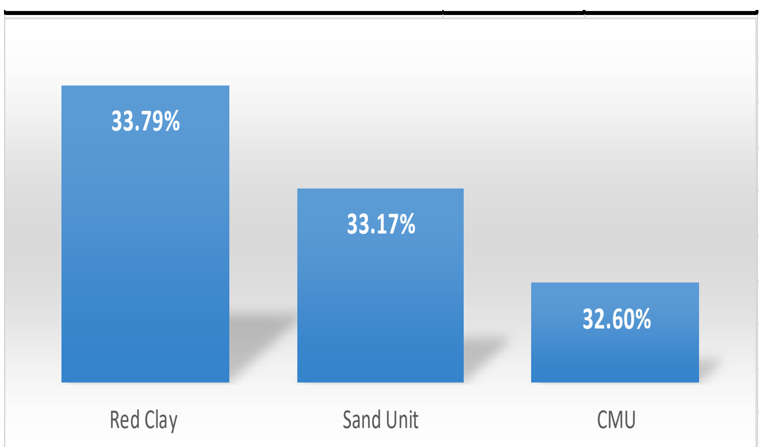

Figure 7- Joubal alternatives ranking

4 Conclusion

This paper presents study, concepts and design of model for applying Value Engineering (VE) using multi criteria decision making technique, which is Analytical Hierarchy Process (AHP). AHP was applied through two main steps. Applying pairwise comparison for criteria and ensuring the consistency of user's inputs are the first step of applying AHP technique. After getting criteria weights, alternatives are evaluated and ranked based on pairwise wise comparison for each criterion. Case study project is used to demonstrate the use of the developed model and validate its methods and algorithms. Eight criteria were selected to evaluate project's alternatives for the architectural block façade system. AHP algorithm was applied through using Microsoft excel spreadsheet to evaluate both criteria and alternatives. Calculations and final ranking reports are created automatically upon inserting the pairwise comparison values. The developed model, techniques and processes enhance VE utilization. This model is expected to enable project team members to conduct value analysis in addition to generating alternatives ranking reports in a timely and easy manner.

References

Al-Harbi, K. 2001.Application of the AHP in Project Management. *International Journal of Project Management*, **19**(1): 19-27.

Al-Khalil, M., I. 2002. Selecting the Appropriate Project Delivery Method using AHP. *International Journal of Project Management*, **20**(6): 464-469.

Baha, B. Y, Wajiga, G. M and Blamah, N. V. and Adewumi, A. O.2013.Analytical Hierarchy Process Model for Severity of risk Factors Associated with Type 2 Diabetes. *Academic Journal*, **8**(39):1907-1910.

Canadian Society of Value Engineering, CSVE, 2016. < http://www.scav- csva.org/index.php>.

Cooper, O.2012. The Analytic Network Process Applied in Supply Chain Decisions, in Ethics, and in World Peace. *PhD Dissertation*, Faculty of Katz School of Business, the University of Pittsburgh, USA.

Davis, E.2004. Finding Value in the Value Engineering Process. *Journal of Cost Engineering*, **46**(12):24-27.

Dell Isola, A.J. 2013. Better Utilizing Value Engineering in Project Delivery. *AACE International Transactions*, PM.1417.

El-Misalami, T., Wlaters, R. and Jaselskis, E. 2006. Construction IT Decision Making Using Multi attribute Utility Theory for Use in a Laboratory Information Management System. *Journal of Construction Engineering and Management*, **132**(12): 1275-1283.

Fong, P. S., and Choi, S. K. 2000. Final Contractor Selection using the Analytical Hierarchy Process. *Construction Management and Economics*, **18**(5), 544:550.

Fong, P.S. 1998.Value Management Applications in Construction. *AACE International Transactions*, VE.02.

Garrido, J.S. 2013. Conceptualizing Value for Construction: Experience from Social Housing Projects in Chile. *PhD Thesis*, Loughborough University Institutional Repository, Loughborough, England.

Gilleard, J. D., and Wong, Y. P. 2004. Benchmarking Facility Management: Applying Analytic Hierarchy Process. *Facilities*, **22**: 19-25.

Manosur, F and Hulshizer, A. 1997. The Antidote to Value Engineering Phobia. *AACE International Transactions*, VE&C.02

Mao, X. 2008. Framework of TRIZ-enhanced- Value Engineering Analysis and its knowledge Management. *PhD Thesis*, University of Alberta, Canada

Miles, L.D. 1972.*Techniques of Value Analysis and Engineering.* 2nd ed., McGraw-Hill, New York, USA.

Neidecker, H. 2010.Value Engineering Applications in Construction. *AACE International Transactions*, CSC.S01

Rains, J. 1999.Value Methodology Standard. *Joint Cost Management Societies Proceedings*, SAVE.01.

Raj, H. 2002. VE Is Not a “Group Cost Cutting”. *AACE International Transactions*, CSC.17.

Saaty, T. L. 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill, New York, USA.

Saaty, T. L.1994. How to Make a Decision - the Analytic Hierarchy Process. *Interfaces*, **24**(6): 19-43.

Saaty, T.L. 2008. Decision Making with the Analytic Hierarchy Process. *Int. J. Services Sciences*, **1**(1):83-98.

SAVE, Society of American Value Engineers International 2007. Value Methodology Standard and Body of Knowledge, *Report*.

Shen, Q. and Liu, G. 2003. Critical Success Factors for Value Management. *Journal of Construction Engineering and Management*, **129**(5):485-491.

Shen, Q., Lo, K., and Wang, Q. 1998. Priority Setting in Maintenance Management: a Modified Multi-Attribute Approach using Analytic Hierarchy Process. *Construction Management and Economics*, **16**(6): 690-695.

Younker, D.L. 2003. *Value Engineering Analysis and Methodology*. Marcel Dekker, Ltd., New York, USA.