Integrated Computational Model in Support of Value Engineering

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ABSTRACT

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Value Engineering (VE) is frequently applied to construction projects for better recognition of project scope and for elimination of unnecessary cost without impacting the functional requirements of individual components of constructed facilities. A critical phase in the application of value engineering is the multi-attributed evaluation of generated alternatives in the speculative phase. Cost is an essential criterion that plays an important role in the selection of the optimum or near optimum alternative that guarantees best value based on the criteria used in this process.

Limited work has been carried out for automation of this process but yet without adequate visualization for the components being considered. This thesis presents an integrated model for building construction that provides professionals, owners and members of VE teams with automation capabilities to evaluate and compare different design alternatives of project components. A BIM model, allowing 4D presentation of the project alternatives is implemented in the proposed model to automate data extraction for project cost estimating and to facilitate and support the visualization capabilities. The model is expected to assist members of VE teams not only in costing each alternative

being considered, but also in ranking competing alternative using multi-attributed criteria in a timely manner.

A prototype model that integrates the project BIM model with RSMeans cost data and AHP has been developed. Cost estimates are generated making use of direct link with RSMeans and the ranking of alternatives is performed using the Analytic Hierarchy Process. The model has been applied to a case project to demonstrate its use and capabilities. The model evaluates and ranks generated alternatives in its output report.

For: Elaheh Reza

Mohammad

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First and for most I am so thankful to my dear God for providing me with everything I am looking for in my life and helping me to reach my goals.

I wish to share this thesis with my family; my mother, father and my husband. My beloved mother for her continuous support without questioning and for always being there for me.I also thank my husband who has been my best friend all my life and especially for the last two years. He stays beside me every day of being far from my country and my family and every day of writing this thesis.

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Chapter One: Introduction

1.1 General

Selection of the most suitable (near optimum) alternative based on multi-attributed criteria has always been an issue for design professionals and owners. There is no universal answer to this problem since the selection criteria and their relative weights vary from one project to another, in order to satisfy owners' construction needs and project targeted objectives. The main objective of this research is to propose an integrated model that provides users with an automated and comprehensive computational platform that considers a wide range of aspects for evaluation and selection of near optimum alternatives that satisfy the owners' requirements.

A BIM model supporting visualization capabilities is used in the proposed model so as to help users visualize project alternatives and be aware of the consequences of the changes they make on every alternative in a timely manner. Moreover, BIM allows 4D modeling of the project alternatives in which cost has been added as the fourth dimension. The model also provides quantity takeoff and schedule of components. In other words; a set of tools and techniques have been integrated in this decision support model in order to assess several alternatives and support designers/owners in making a value driven selection among generated alternatives.

1.2 Research Motivation

Value engineering (VE) is a problem solving technique; aims to produce various alternatives for a project and/or its subsystems and components based on predetermined functions and then chooses the optimum or near optimum alternative that best addresses the problem. Value Engineering is frequently applied to construction projects for better project scope recognition and for elimination of unnecessary cost without impacting the functional requirements of individual components of constructed facilities. A critical phase in the application of value engineering is generating innovative alternatives along with the evaluation of generated alternatives based on defined criteria for that purpose. Limited work has been carried out for the automation of this process but yet without adequate visualization for the components being considered. VE considers design alternatives, cost estimating and project driven objectives structured in a suitable selection criteria. VE brings an opportunity for owners and stakeholders of constructed facilities to participate in the design development and to cooperate in the decision making process to select the best project alternative that fulfill their targeted objectives. (CSVE, 2012).

This thesis presents an automated model for design professionals, owners and members of VE teams to evaluate and compare different design alternatives of project components using multi-attributed criteria as well as integrating that model with visualization capabilities to assist designers and stakeholders in making related decisions. The motivations to conduct the current research are:

- To develop a model that can be of help to the value engineering team members in making value oriented decisions
- To automate the process of alternative evaluations

- To improve the visualization capabilities that can be used in the speculation phase of value engineering and helping in generating innovative alternatives
- Help designers, owners and members of VE team have a similar picture of the project and can communicate with each other at the early phases of the project thus they can agree on selecting an alternative that can address owner's requirements of the project, suits owners desired criteria and satisfy designers. Moreover it proposes subsystems and components for each group respectively.
- To help owners in defining criteria for the different projects they want to complete by categorizing building types and offering certain criteria for each building type
- To be able to track the consequences of the changes VE team make on every alternative and to be able to follow up the results so they can build the alternative while they are aware of the effect of any single change
- Make the most benefit from BIM model and to embed the desired defined criteria in the model
- To address the qualitative evaluation of criteria and to find out their quantify weight. Some criteria have a qualitative nature which makes their quantitative evaluation exceptionally difficult.

1.3 Research Objective

The research aims to propose an automated model for designers/owners and members of VE teams to evaluate and compare various alternatives of a project based on the predefined criteria (focused mainly on the project cost). A set of tools and techniques are integrated in a model in order to assess several alternatives thus choose the most optimum one.

The other objectives that augment the main goal are:

- Study and implement the evaluation phase of the value engineering job plan
- Identify, study and weight criteria related to each building type
- Study and extend the use of BIM models to collect input data for the assessment model and to assist in the automating evaluation process
- Provide and improve the visualization capabilities both in the speculation phase and evaluation phase of the VE job plan
- Study and use the Uniformat II in order to categorize data
- Develop a 4D model to automate the cost estimation of the alternatives
- Embed the AHP algorithm into the computing model to rank the alternatives
- Programmed a computational platform to link the data extracted from the BIM model to the RSMeans cost data and provide the cost estimating eventually

1.4 Thesis Organization

Chapters of the thesis are organized in a way that address the research objectives and introduced the proposed model properly.

Chapter two presents a review of the literature in value engineering methods along with Building Information modeling (BIM), Cost estimating, Multi Attribute Decision Analysis.

The method proposed in this dissertation is presented in detail in Chapter three. Chapter four describes the automated computational platform developed to implement the proposed method; the user friendly coded application, and its implementation is also described in chapter four. As a proof of concept, a case study is presented in chapter five. Chapter six includes the summary and concluding remarks of this research. Contributions and limitations of the proposed method along with recommendations for future research work are also included in this chapter.

Chapter Two: Literature review

2.1 General

Value engineering (VE) is a problem solving technique; aims to produce various alternatives for a project based on predetermined functions and then chooses the optimum or near optimum alternative that best addresses the problem. It considers design alternatives, cost estimating and project driven objectives structured in a suitable selection criteria. VE brings an opportunity for owners and stakeholders of constructed facilities to participate in design development and to cooperate in decision making process to select the best project alternative that fulfill their targeted objectives. (CSVE, 2012).

The value methodology is commonly applied under the names Value Analysis (VA), Value Engineering (VE), and Value Management (VM) which are used interchangeably in this thesis (SAVE, 2007). The use of functional analysis to tackle the problems, distinguishes this method from other value improvement methods (CSVE, 2012).

An extensive literature review on different topics has been conducted to improve the application of value engineering and propose an integrated model that provides users with an automated and comprehensive computational platform that considers a wide range of aspects for evaluation and selection of near optimum alternatives that satisfy the owners' requirements. The lists of the literatures that are reviewed and presented in this chapter are summarized in Figure 2-1.

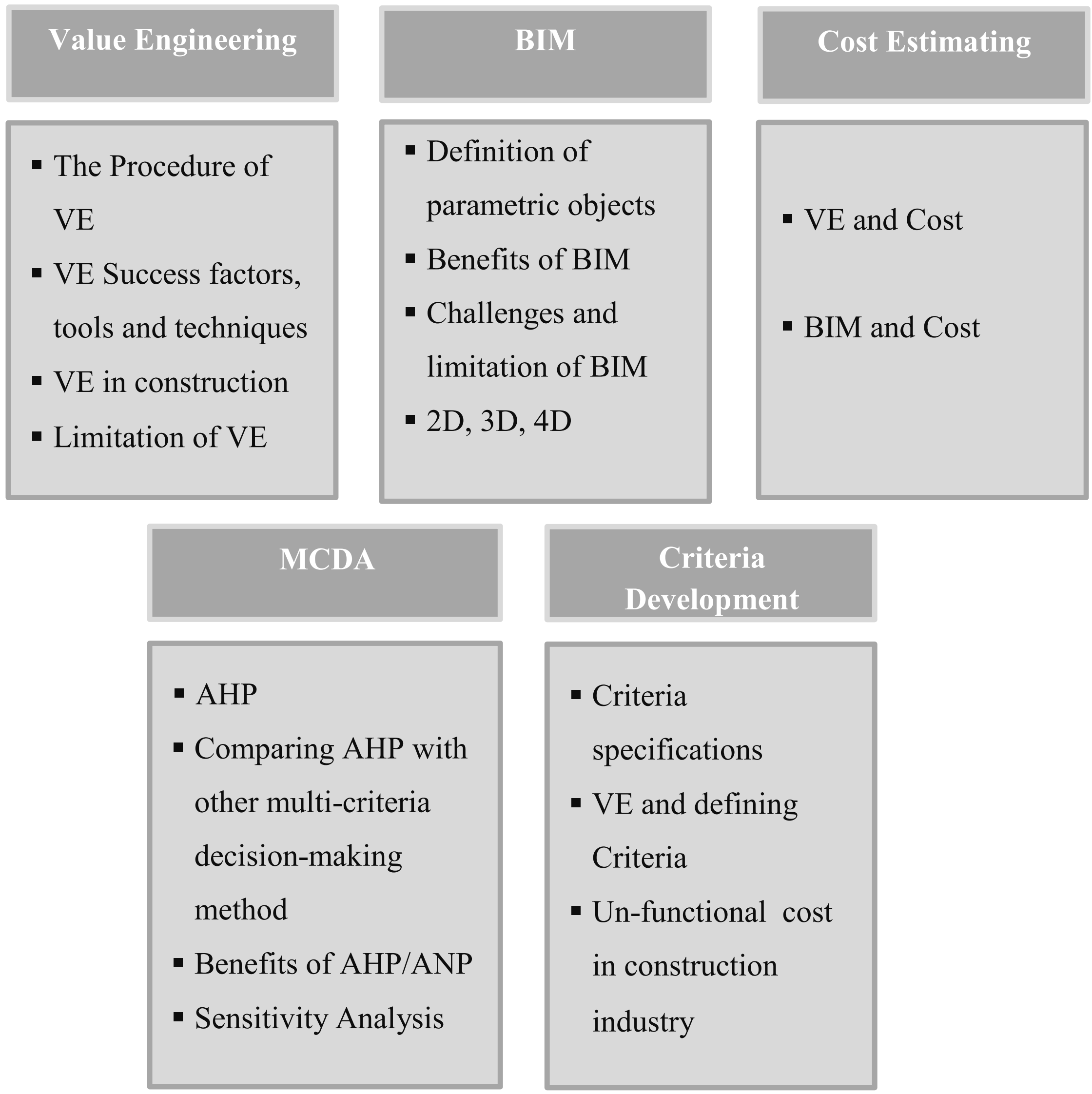


Figure 2-1-Literature Review Summery

The application of value engineering needs a decision making environment in order to translate the preference levels of the elements in the selection process into a numerical scale. Analytic Hierarchy Process (AHP) is a Decision Making tool that has been used in the thesis proposed model.

Building Information Modeling (BIM) has been proved to be of great benefit for the Architecture, Engineering and Construction (AEC) industry. It allows the integration of design and construction while lessening the cost and duration of the project (Eastman, et al., 2011).

2.2 Value Engineering

Value engineering is a problem solving method applies to decision making systems. It is a creative approach and organized effort that uses particular tactic, a body of knowledge and an educated team in order to get better project scope recognition and identify unnecessary cost. It helps to eliminate the cost that does not satisfy either quality or technical or functional requirements (Scott, 2010). Value Analysis (VA), Value Engineering (VE) and Value Methodology (VM) are the terms of value engineering and they can be used interchangeably in the context of this thesis. (SAVE, 2007)

Value engineering was first introduced by Lawrence D. Miles during the World War II when he was an employee of the General Electric Company and the company was facing difficulties producing their products. Because of the essential materials shortage, he was led to develop an approach which consumed less materials and money while producing the same function of products. He conceived the function analysis concept which later was improved to an innovative process called value engineering (SAVE, 2007). Close to 15 to 20 percent of the manufacturing cost and even much more can be reduced without compromising clients' value by using the VE method. It now applies to all branches of enterprise engineering, procurement, marketing and management (Miles, 1972)

2.2.1 Value Engineering Procedure, Success Factors, Tools and Techniques

Philosophy of the value analysis is to supply the human being with sufficient tools to accomplish their work in a timely manner. That is to say every job can be done more effectively if the needed tools are well provided. “The most skillful golfer also wants precisely the best club available for the particular shot he is making” (Miles, 1972). New ideas, processes, products and materials can be of help to establish desired clients value at lower cost (Miles, 1972).

So as to improve value, value methodology creates a structured procedure called *Job plan.* Problems are recognized and tackled based on their functions in the job plan (Miles, 1972). It is organized in a five step process (See Figure 2-2). Table 2-1 listed the job plan procedure as described by DOD and GSA hand books in different years (O'Brein, 1976).

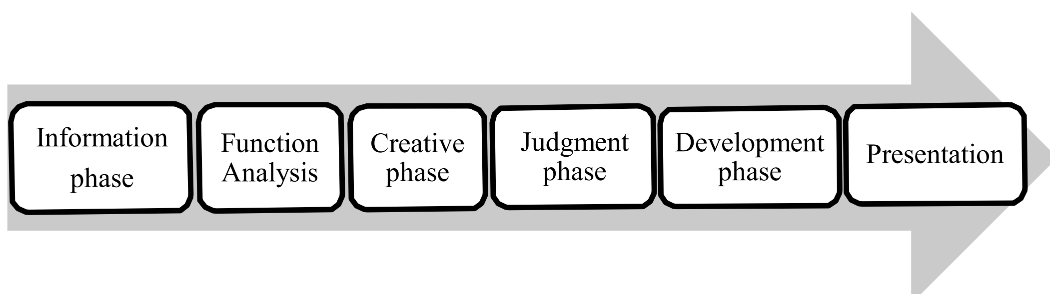


Figure 2-2- VE Job Plan

1. **Information phase:** The efficiency of value engineering is relying on the information step. A list of required facts, assumptions (beliefs) and information about the project should be made. The situation should be saturated with as much information as possible.

2. **Analysis phase:** In order to define the project scope and clarify the basic functions, VE team members use function analysis. Using function analysis the efficiency of the functions could be improved and potential significant cost savings would be achieved. This step will focus on essential "function"; Functions would be evaluated, and a detailed problem setting would be provided afterwards. Function Analysis is also referred to in mathematics and linear operation which is not the case in the context of this thesis.
3. **Creative phase:** Extensive range of possible alternatives and methodologies to overcome the problem should be considered regardless of any judgmental and criticizing approach.
4. **Judgment phase (Evaluation):** In this step the number of generated alternatives and ideas would be reduced, focusing on the value oriented solution that would meet the owners' preferred criteria. (SAVE, 2007)
5. **Development phase:** Final step towards implementation and development of selected alternative would be made here.

In the first three sequential steps, you cannot proceed to the next step unless that phase is exhaustively accomplished. Being engaged in several activities during each phase of the job plan, VE team will be encouraged to recognize and categorize ideas and generate more alternatives. In order to better conduct the VE job plan, Society of American Value Engineers International (SAVE) proposes two generic steps to be accomplished before and after the job plan (See Figure 2-3):

Table 2-1-VE Job Plan History- (O'Brein, 1976)

L.D. Miles 1961 (Miles, 1961)	**DOD HANDBOOK 5010.8-4 (1963)**	**DOD (USA META) 1968**	**E.D. Heller 1971** (Heller, 1971)	**A.E. Mudge 1971** (Mudge, 1971)	**GSA.PBS P 8000.1 1972**	**L.D. Miles 1972** (Miles, 1972)	**PBS VM workbook 1974**	**SAVE International 2003** (SAVE, 2007)
Orientation		Orientation		Project selection	Orientation	Information	Information	Information
Information	Information	Information	Information	Information	Information	Analysis	Function	Function
Speculation	Speculation	Speculation	Creative	Function	Speculation	Creation	Creative	Creative
Analysis	Analysis	Analysis	Evaluation	Creation	Analysis	Judgment	Judicial	Evaluation
Program planning	Development	Development	Investigation	Evaluation	Development	Development	Development	Development
Program Execution	Presentation	Presentation and follow-up	Reporting	Investigation	Presentation		Presentation	Presentation
Summary and conclusion			Implementation	Recommendation	Follow up		Follow up	

1. Pre-Workshop preparation

The purpose of this step is to organize and design the value study. The question is "what has to be done for a value study?" Some of the activities to be done in this step can be listed as: Illustrate clear scope and objective of the VA, Collect data and information needed, Acquire the work definition, drawings, specification, reports and project estimation, Make a hierarchical structure of project concerns, Identify VA team members,

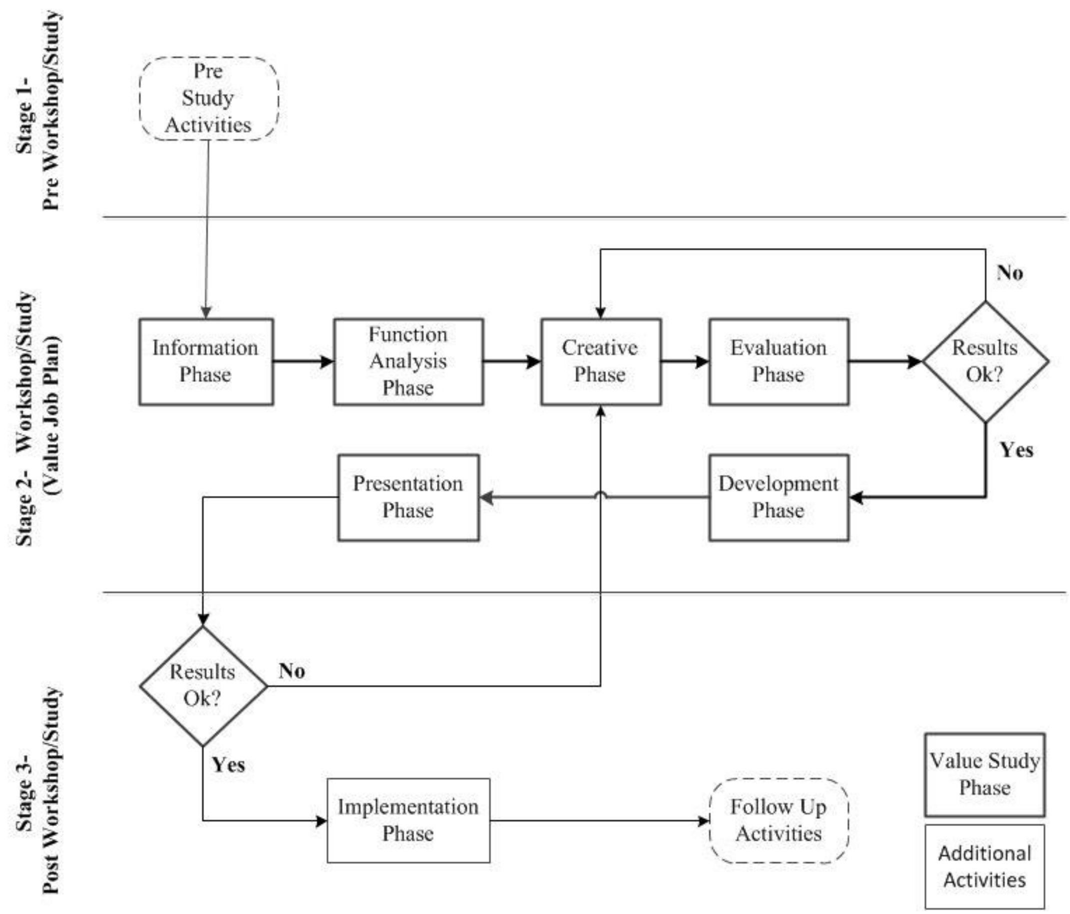


Figure 2-3- Value Study Additional Activities - (SAVE, 2007)

Provide diagrams for the problems. The favorable result of this workshop is to understand and determine what needs should be addressed and would be the priorities (SAVE, 2007).

In this step the value team members bring to the table the needed expertise for the disciplines being considered, including operation and maintenance. This can be from within owners' organizations or external if the required expertise is not available.

2. Value Workshop which applies in the five Phases of the Job Plan explained above.

3. Post-Workshop documentation and implementation

This workshop aims to follow up on execution of the value analysis and to improve its implementation for next VAs.

The impression of the people who are not involved in the VA would be that value analysis techniques are likely to decrease the appearance and attractiveness of a product in order to reduce cost. Contrary to this impression value engineering is a value oriented procedure results in an improvement of the products.

To be unusually successful in a Value study one should consider several factors. To properly manage limited resources of time, manpower and money, critical success factors (CSFs) of the projects should be identified (Chua, et al., 1999). VE objectives are determined based on clients' preference and by the help of VE facilitators. It is influenced by so many factors such as details of the projects and expectations of the clients. Clarification of the project's goal is essential for the VE team since it addresses the process of VE and help them to be focused where it is needed (Qiping Shen, 2003).

Miles (1972) Listed acceleration factors to get better cost results while retaining high grade performance. Some of these items are listed below: provide information only from the best source, blast the situation, minimize disadvantages, be creative, think of new and better solutions, find stoppers or roadblocks, do not allow to be influenced by the stoppers, help cooperate with industry (Miles, 1972).

Qiping Shen and Guiwen Liu (2003) identify critical success factors and categorize them based on the ordinary procedure of VE (See Table 2-2). They have added two more factors "clear objective of the study" and "professional experience and knowledge of the participants" to the previous relevant researches. The first one has been proved to be helpful for a variety of objectives and not only for cost saving projects. The results reveal that the success of VM studies depends on combined effort from all parties, clients and facilitators who are directly or indirectly involved in studies (Qiping Shen, 2003).

Table 2-2-CSFs - (Qiping Shen, 2003)

Groups	**Factors**
Preparation of workshop	1. Clear objective of VM study
	2. Qualified VM facilitator
	3. Multidisciplinary composition of VM team
	4. VM experience and knowledge of participants
	5. Professional experience and knowledge of participants in their own disciplines
	6. Personalities of participants
	7. Preparation and understanding of related information
	8. Timing of VM study
VM workshop Job Plan	9. Structured job plan
	10. Control of workshop
	11. Attitude of participants
	12. Presence of decision takers
	13. Interaction among participants
	14. Function analysis
	15. The use of relative skills and techniques ~such as FAST, brainstorming, etc.

	16. VM proposals selection and development
Implementation of generated proposals	17. Plan for implementation
	18. Follow-up trailing and support for implementation
Supporting factors	19. Client support and active participation
	20. Cooperation from related departments
	21. Adequate time for study
	22. Financial support
	23. Logistics support

The professional grade value work is the integration of special knowledge with tools and techniques to identify the problem and organize it into a solvable structure. The knowledge required to improve the value work is "information on materials, processes, functional products, sources of functional knowledge, approaches to function performance and practical ideas for economical function solutions" (Miles, 1972). The Best value alternative, known as reliable performance at the lowest cost, is only reachable through the best combination of materials, techniques and ideas.

Construction industry applies VE in its projects for more than half a century now and it still uses the traditional pattern (Zhang, et al., 2009). The success or failure of the VE study highly depends on the creative phase of the VE job plan. Instead of using the traditional brainstorming technique to generate ideas and solutions, Xueqing Zhang has developed a value engineering knowledge management system (VE-KMS) to support knowledge creation process and to retain the historical data of the VE studies and use these data in the construction industry. The knowledge management system (VE-KMS) uses the theory of inventive problem-solving (TRIZ). TRIZ is a methodology and a problem solving technique used for creating new ideas and solutions. Incorporation of TRIZ tools in the VE process would improve the effectiveness of VE in the creative phase of VE (Zhang, et al., 2009). This attempt will significantly enrich the creative power of the VE team and consequently results in better decision making.

Moreover, VE-KMS allows automation of collecting and condensing knowledge procedure. Using the historical VE ideas stored in the database, KMS avoid repeated work in a studied domain.

Various models of VE have yet been developed and applied in the construction industry. Construction projects are highly dependent on the qualitative decision making process due to experts' subjective judgments. To minimize subjective opinions of VE teams members and to be able to better estimate projects' cost and time, construction simulation technique (CYCLONE) can be applied to construction projects. The simulation technique uses quantitatively derived data from the simulation analysis and will improve Value engineering decision making process (Chung, et al., 2009). In the construction industry, productivity estimation plays an important role in VE team proposals. Using simulation analysis can be of help to VE team member to compare the estimated value with the actual amount in a structured framework and to identify effective alternatives to the original plan. (Chung, et al., 2009).

It has been proved that in order to well conduct the value study, two separate types of work must be accomplished. First is to identify the unnecessary cost that does not satisfy either quality or other technical and/or functional requirements of the project. Second, decision making of the appropriate value alternative that brings most benefit to the project.

In addition to special knowledge, sufficient tools and techniques are also needed so as to generate creative alternatives. The model proposes in the methodology can be of help to produce creative alternatives from which a choice can be made. To accomplish the clients' desired functions, the creative concepts and essential knowledge should be integrated to provide customers with several function alternatives. In order to accelerate the creative activities firm action is needed. That is to say, every part of the VE job plan should be effectively used to achieve a high degree of value.

2.2.2 Value Engineering in Construction

Construction projects could benefit from value engineering in different phases of the construction from conceptual design and development to preliminary and final design, procurement and construction (Miles, 1972). Value engineering can be applied at any phase of the project life cycle; however it has been proved that it has the most benefit during the early stage of the project (O'Brein, 1976). See Figure 2-4.

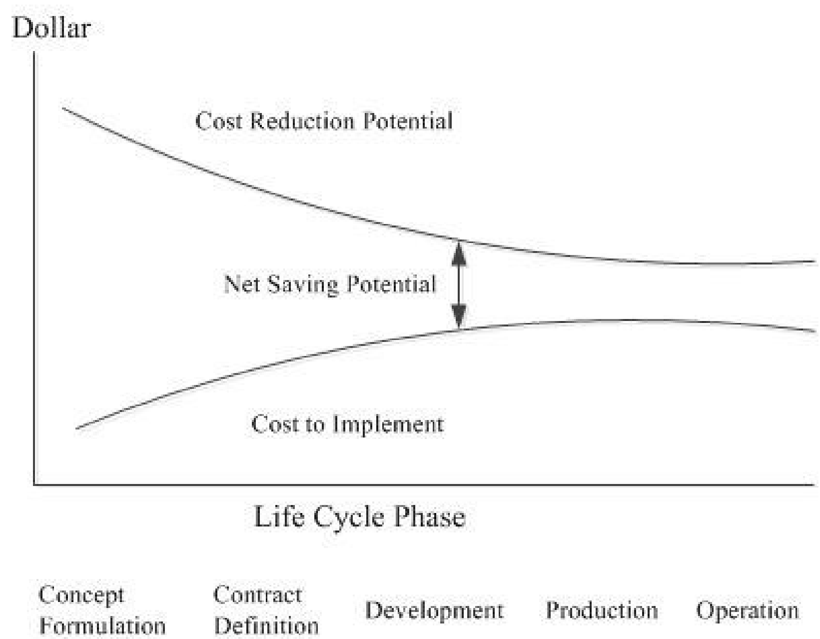


Figure 2-4- VE Benefits During Construction Lifecycle - (O'Brein, 1976)

2.2.3 Value Engineering and Cost

Value Engineering achieves value by generating appropriate alternatives. It is evident that throughout this process, relative cost plays the most important role. Therefore, a large amount of accumulated relative-cost data is included in the special knowledge of value analysis. The provided cost data will be of help in the selection of materials, processes, and approaches which are needed to accomplish the defined function at lowered cost. Guarantee the maximum value is difficult due to changes to the actual costs of material and the cost of processes and so the relative costs will be changed consequently. However, what is matter in the selection of the alternative with the best value is the change of the relative costs which is far less than the change in actual costs (Miles, 1972). Various factors introduce their own order of magnitude of costs such as a design approach considered for the application of the function; material and process are included in the special value analysis knowledge (Miles, 1972).

2.2.4 Limitation of Value Engineering

The value is determined as a ratio between performance and cost. To improve the value either performance should be improved or the cost should be reduced. *Performance-oriented* work is focused on accomplishing the desired functions and *value-oriented* work is centered on accomplishing functions using less of the resources. Performance-oriented work is more effectively completed comparing to value oriented work due to lack of measurement tools for value-oriented works. Performance-oriented works are based on measurements and tests while there is no immediate way of making the results of poor or good value evident. Hence there is a need for a value oriented model which takes all the aspect of value into account.

Since value analysis aims to complete the total function for lowest overall cost, it is essential to provide measures of the value of the function. One technique of assessment of the function is by comparison. However, this evaluation should not be made by comparison with the past. 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).

By answering the questions such as how else the function can be accomplished? Or how much would that cost? You can avoid the danger of judging and planning the future from the past will be. Evaluations are the outcome of the comparison in different kinds. In some cases it is compared to standards in other instances, it is the comparison with similar items; and in others, a comparison with partially similar items.

Regardless of how diligent and innovative the value analyst is, there are always alternatives that are not taken into consideration. Numerous other alternatives can be generated which they all can satisfy the project objectives. It is understood from the foregoing that the value specialists’ problem is yet to generate various alternatives and to evaluate them to select the optimum alternative. If functions have not been identified and those determined function are not evaluated based on the comparison then the process is mainly cost analysis rather that value analysis.

2.3 Building Information modeling (BIM)

BIM is defined as the creation of coordinated, consistent and computable parametric data about a building project; So as to use in design decision making, high-quality construction document production, building performance prediction, cost estimation and construction planning (Krygiel, et al., 2008). BIM is introduced as a dramatic transition from the traditional design delivery process to a more integrated procedure. Aside from the 3D rendering of a building, BIM has combined design technologies to represent building components in a virtual environment (Eastman, et al., 2011).

The BIM Handbook presents BIM as a modeling tool to produce, communicate and analyze building models. Building models are recognized as "Building components that are represented with digital representations (objects) that carry computable graphic and data attributes that identify them to software applications, as well as parametric rules that allow them to be manipulated in an intelligent fashion." (Eastman, et al., 2011) Data are consistent and not redundant, so that every change applies to components is represented in all views. According to National Building Information Modeling Standard (NBIMS) Committee of the National Institute of Building Sciences (NIBS) Facility Information Council (FIC), BIM is "an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle." (NIBS 2008) (Eastman, et al., 2011).

An accurate quantity takeoff, the schedule of components, count of items and area and volume of spaces can be extracted from a BIM model at any phase of design and can be used for cost estimating. Moreover, Value analysis process become easy to implement in the design stage, thanks to the list of components generated by BIM .Cost items which used to be eliminated at the end of the projects in the traditional practice are now evaluated in the design process through the BIM model (Eastman, et al., 2011).

A complete 3D data base that can be used for cost estimating, scheduling, detailing, advance bill production, automated shop drawing and construction planning is provided by a BIM model (Edgar, 2007).

2.3.1 Definition of Parametric Objects

To well understand BIM and to compare it to traditional 3D objects the concept of "Parametric Objects" should be understood. In 1980sObject-based parametric modeling developed for manufacturing. "It does not identify objects by fixed geometry and properties rather, it represents objects by parameters and rules that determine the geometry as well as some non-geometric properties and features. The parameters and rules can be expressions that relate to other objects, thus allowing the objects to automatically update according to user control or changing contexts. "

BIM provides the opportunity to carry out specific tasks as "tool", along with a "platform" for managing the data within a model for different uses. Data can also be managed in other models, a BIM "environment". A BIM application answers one or more of these services.

Tool level varies in different BIM models based on the sophistication of their predetermined objects. It differs regarding the ease to define new object classes; methods apply to update objects; ease of use; various types of surfaces that can be used; drawing capabilities; allowing large number of objects. In terms of *platform* level, the ability to manage large projects or projects with many details; the interface with other BIM software systems; the consistency of the interface while using too many tools; the ability to support collaboration, are vary in different models (Eastman, et al., 2011).

BIM objects are determined as below (Eastman, et al., 2011):

- Contain geometric definitions and associated data and rules.
- Always consistent as the geometry is integrated non-redundantly. Plan, elevation and section of a single component are always consistent. Dimensions should match.
- Parametric rules that control objects, modify its related geometric automatically when it inserts into a building model or when any change apply to that object. For instance, a door or a window will fit into a wall automatically; a light switch will locate to the proper side of a room as soon as a light the light entered in the room. The wall height will be adjusted to the ceiling height and so forth.
- Objects can be defined as several hierarchical levels. A wall along with its components can be defined at different level of aggregation. So if the weight of a component related to wall change, the weight of the wall will change consequently.

- If the change applies to an object violates object feasibility in terms of size, constructability and so on, objects' rule will identify them.
- Objects are able to link to or receive or broadcast or export sets of attributes. Structural materials, acoustic and energy data can be linked to their models and applications.

"Technologies that allow users to produce building models that consist of parametric object are considered BIM authoring tools" (Eastman, et al., 2011)

2.3.2 Benefits and Challenges of BIM

Benefits of BIM model are (Krygiel, et al., 2008):

- 3D Simulation Vs. 2D Representation

A two dimensional (2D) drawing is simply a representation of the final project, composed of plans, sections, and elevations while BIM allows three dimensional (3D) of the building and its components. This ability goes beyond demonstrating how different building assemblies can be combined in the project. It can predict collisions, show construction variables on different building designs, and calculate material quantities and time periods.

- Accuracy Vs. Estimation

BIM gives the opportunity to build the whole project virtually prior to the construction. It augments the level of accuracy both quantitatively and qualitatively to compensate the limitation of traditional design and documentation.

- Efficiency Vs. Redundancy

Elements are drawn only once in the BIM model in the plan view and the projection of all elevations and sections will be generated automatically. This prevents the redundancy in the drawing while giving the designer the opportunity to focus on design rather than spending time on the drawings.

Other benefits of BIM numbered by Azhar are (Azhar, et al., 2008):

- Faster and more effective processes; Information is shared easily, can be value-added and reused
- Better design; building alternatives can be thoroughly analyzed, simulations can be performed quickly and performance evaluated, so it enables improved and innovative solutions
- Controlled whole-life costs and environmental data; environmental performance is more predictable, lifecycle costs are better understood
- Better production quality; documentation output is flexible and apply automation.
- Automated assembly
- Better customer service; taking advantage of accurate visualization, alternatives can be understood better
- Lifecycle data; facilities management benefits form requirements, design, construction and operational information

Stanford University Center for Integrated Facilities Engineering (CIFE) figures based on 32 major projects using BIM, mentioned BIM benefits as (CIFE, 2007):

- Up to 40% removal of unplanned change
- Cost estimation accuracy within 3%
- Up to 80% time saving to generate a cost estimate
- A savings of up to 10% of the contract value over clash recognitions
- Up to 7% time saving in project

BIM Handbook summarizes BIM benefits as (Eastman, et al., 2011):

- Coordinate design documentation
- Simulate construction process and operation activities prior to physical implementation
- Drive out problems and predict performance
- Coordinate the construction to reduce construction time and eliminate change orders
- Facilitate data entry as part of the construction business process and then re-uses it throughout the whole project lifecycle and beyond

Challenges and Limitations of BIM

According to the valid results of a questionnaire, sent to 100 AEC academics and practitioners in the USA and UK, about 40% of respondents from the US and about 20% respondents from UK declares that implementation of BIM requires lots of time and training of the human resource (Yan, et al., 2008). Decisions in organizations are mainly made based on a business perspective (make a profit). The AEC industry is not invested on BIM, due to the limited work carry out on the financial aspect of BIM and few numbers of case studies in that area. Moreover inherent resistance to change, as lots of architects are satisfied with the current methods of design and are not willing to accept new functions and benefits if BIM (Yan, et al., 2008). The results of the questionnaires are illustrated in Figure 2-5:

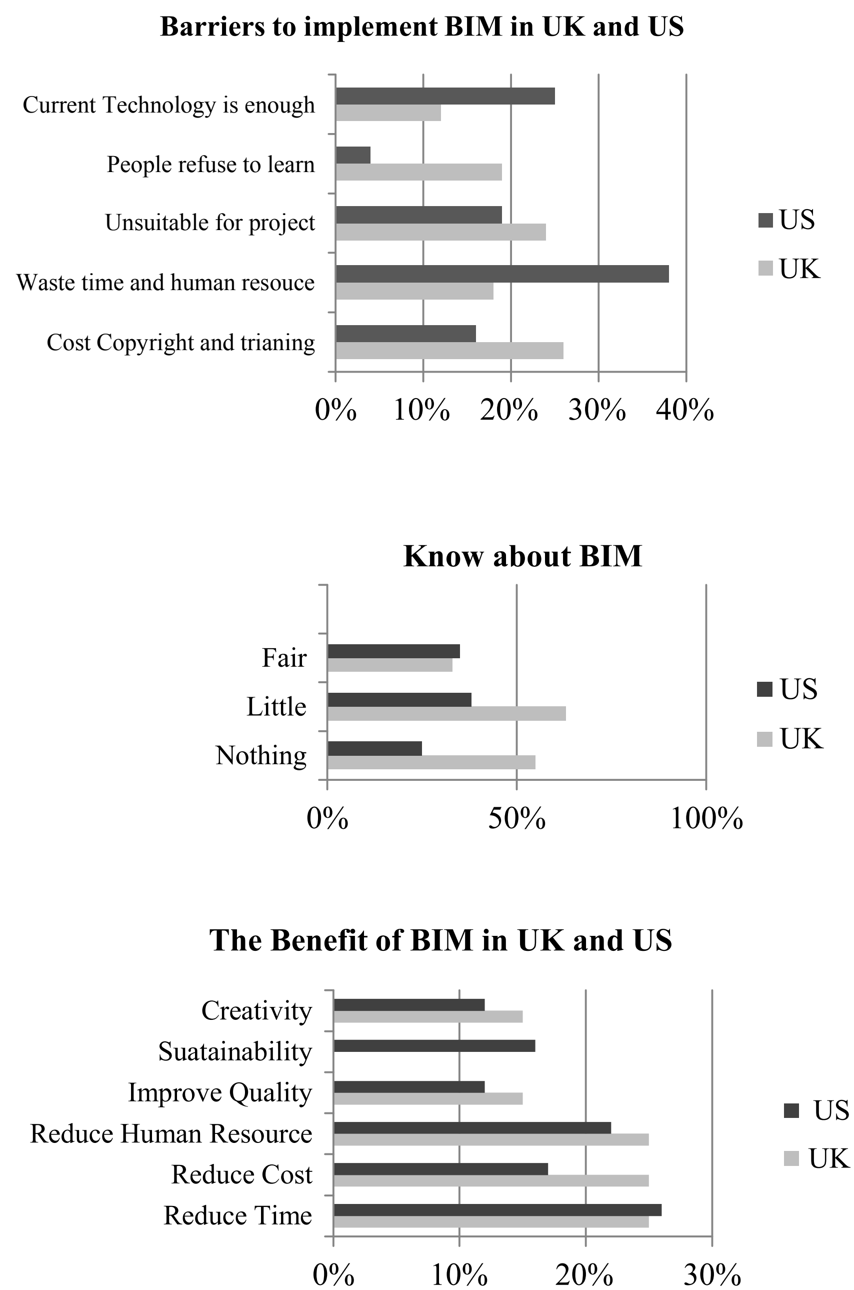


Figure 2-5- Challenges of BIM- (Yan, et al., 2008)

The survey illustrates that more than 60% of experts in the UK know little about BIM; more than 30 % of them know nothing and 5% declare they have fair information about BIM. These figures found to be 39%, 28% and 35% in US survey respectively. The major barrier to implement BIM is seen in the US which is the Waste of time and human resources followed by insufficient technology and not being suitable for the projects. The cost that should be allocated for training, copyright and people who reluctant to learn new softwares are other obstacles to apply BIM widely. On the other hand, benefits found in the questioners are: reduction in time, cost and human resources along with improvement in quality, creativity and sustainability.

The productivity and economic benefits of BIM are undeniable for the AEC industry. Moreover, the technology needed to implement it, is progressing steadily. However it is not adopted as much as anticipated (Azhar, et al., 2008). As Bernstein and Pittman mention in Autodesk Building Solutions Whitepaper 2005, there are technical and managerial barriers for BIM to be implemented (Azhar, et al., 2008). Regarding technical reasons, it was mentioned:

1. Data interoperability issues; so a well-defined transactional construction process model is needed.
2. Digital design data should be computable.
3. Integration of meaningful information among BIM components should be developed.

In terms of management issue is the absence of a clear consensus to implement BIM. An organization that considers it as a whole is needed. Another argues among the AEC industry stakeholders (i.e. Owners, designers and constructors) are who should take the responsibility to develop and operate the building information models and how should the costs be distributed? (Azhar, et al., 2008). A great number of scholars, practitioners, software vendors and professional organizations are working to resolve these challenges and it is expected that the use of BIM will continue to increase in the AEC industry.

2.3.3 Visualization Models

Rapidly changing of the construction industry makes owners and contractors to embrace new business models and technologies to provide them with competitive advantages; they should address the need for efficiency, short delivery time and high quality. A critical part of this wave is the integration of processes and improved communication from design to construction (13Vi).

For thousands of years, 2D graphic representations have been the only form of communication. During the early 20th century graphical standards for 2D illustrations came into effect. Some advantages to standardizing particularly in the 2D Multi view area were (Cory, 2001):

- The ease to construct
- Concerned with only 2 dimensions in single views
- Provide true size and shape for features

- Most accurate types of engineering graphic

The disadvantages were:

- Incapable of visualization
- Required interpretation
- Limited usage

Griffis, Hogan and Li listed several benefits for utilizing 3D CAD (Cory, 2001):

- Checking clearances and access
- Visualizing details from non-standard viewpoints
- Using the model as a reference during project meetings
- Enabling constructability reviews (Cory, 2001)

What makes BIM famous, were the 3D models. Bringing the visualization capabilities for multi-million dollar projects was reasonably enough for BIM being widespread. As with BIM the projects are constructed twice, once virtually and once on the job site. Once you have the 3D BIM model, you will have the constructability and coordination, 4D Scheduling and 5D costs planning consequently. It starts with 2D drawings then proceeds to 3D models and coordination; then the quantity take off will be used in the 4D and 5D (13Vi). Construction management functions are being integrated into BIM tools. The extension of the 4D CAD to include cost is called 5D CAD and further extended to incorporate additional management parameters to nD CAD are already being undertaken by various solution providers (Eastman, et al., 2011). This brings clarity to project construction regarding feasibility and reliability. Nowadays not only research communities are familiar with the concept of virtual construction but also it has been widely used and appreciated in practice. It is known as “Virtual Design and Construction Survey (VDC)” (CIFE 2007). Vico Office 2010 (VicoSoftware 2010) and Innovaya (Innovaya 2010) are the examples of this trend (Eastman, et al., 2011).

Literatures often indicate the 4th Dimension as time and cost as the 5th Dimension. However throughout the context of this thesis the 4th dimension is assigned to the cost as the time factor has not been considered in the research. 4D BIM is not only a model-based cost estimate method, rather it is a modern tactic to communication with the owners and stakeholders in order to provide an exhaustive data and experience to the project in a visual way.

2.3.4 BIM and cost

The accuracy of a cost estimating relies on a number of factors such as market condition which is changing over time, the time slack between estimation and execution, design changes and quality issue (Jackson, 2002). The accurate and computable inherent of building information models enables a more reliable source for owners and stakeholders to perform quantity takeoff and estimating. This results in faster cost feedback on design changes. During the early stages of the construction project process, particularly in the conceptual and feasibility phases, the ability to affect cost is stronger (See Figure 2-6) (Eastman, et al., 2011).

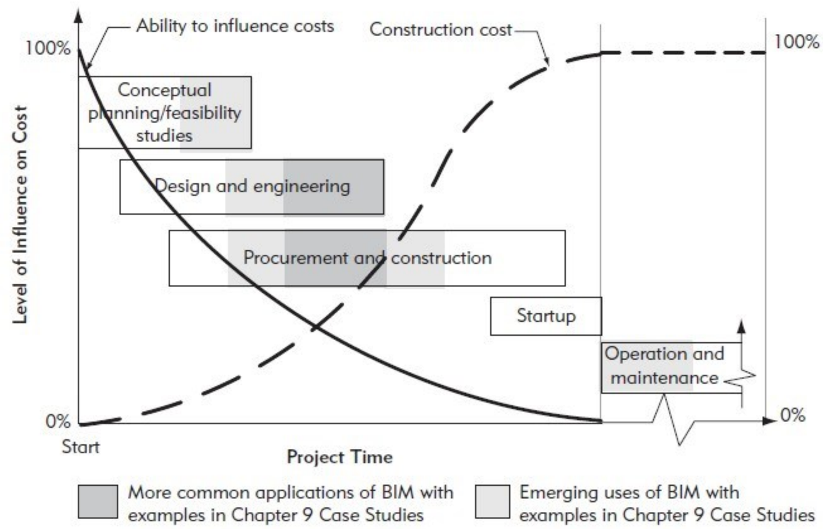


Figure 2-6-Influence of Overall Project Cost over Project Lifecycle -

(Eastman, et al., 2011)

Insufficient time, poor documentation, and communication breakdowns between project participants, particularly between owner and estimator is proved to be the main reasons poor estimates. Integration of an automatic quantity takeoff system with its relational cost data to generate a cost estimating report is a method to address the difficulties of the cost estimate. Quantification requires 50% to80% of a cost estimator's time on a project (Eastman, et al., 2011). Estimators are the backbone of any GC firm. If any portion of the project scope is missed, estimators are the one who is responsible and moreover the whole bid would be at risk. With BIM, it is visual and very comprehensive. Now Estimators are able to assure that they have not missed one iota of scope (13Vi). BIM allows the generation of takeoffs, counts and measurements directly from a model (Sabol, 2008). Currently BIM is used either in the late phase of design and engineering or early phases of construction (Eastman, et al., 2011).

Improving the overall accuracy of cost estimating is the key motivator for implementing BIM-base cost estimating method. Managing cost with BIM applications provide owners with: 1- More reliable estimates early in the process with conceptual BIM Estimating and 2- Faster, better-detailed, and more accurate estimates with BIM quantity takeoff tools (Eastman, et al., 2011).

A consistent definitions and data format for building components and assemblies is a prerequisite to a successful cost estimating. AEC industry improves significant efforts to standardize data models and definitions. It develops consistent frameworks for data interoperability in order to prove common definitions in a common format for the many participants involve in the construction process (Sabol, 2008).

International Alliance for Interoperability (IAI) develops the Industry Foundation Class (IFC) as a data model. It aims to provide a single framework which is accepted internationally. This will facilitate the exchange of information among participants involve in the building process, throughout the entire Lifecycle (Sabol, 2008). A format for classifying building elements and related site-work is UNIFORMAT II. Defined elements, in the Uniformat classification are major components common to most buildings. Using UNIFORMAT II guarantees consistency in the economic evaluation of building projects over time and from project to project. It enhances project management and reporting at all stages of the building life cycle, planning, programming, design,

Table 2-3-Uniformat II Classification- (Charette, et al., 1999)

Level 1 **Major Group Elements**	**Level 2** **Group Elements**	**Level 3** **Individual Elements**
A SUBSTRUCTURE	A10 Foundations	A1010 Standard Foundations A1020 Special Foundations A1030 Slab on Grade
	A20 Basement Construction	A2010 Basement Excavation A2020 Basement Walls
B SHELL	B10 Superstructure	B1010 Floor Construction B1020 Roof Construction
	B20 Exterior Enclosure	B2010 Exterior Walls B2020 Exterior Windows B2030 Exterior Doors
	B30 Roofing	B3010 Roof Coverings B3020 Roof Openings
B SHELL	C10 Interior Construction	C1010 Partitions C1020 Interior Doors C1030 Fittings
	C20 Stairs	C2010 Stair Construction C2020 Stair Finishes
	C30 Interior Finishes	C3010 Wall Finishes C3020 Floor Finishes C3030 Ceiling Finishes
D SERVICES	D10 Conveying	D1010 Elevators & Lifts D1020 Escalators & Moving Walks D1090 Other Conveying Systems
	D20 Plumbing	D2010 Plumbing Fixtures D2020 Domestic Water Distribution D2030 Sanitary Waste D2040 Rain Water Drainage D2090 Other Plumbing Systems
	D30 HVAC	D3010 Energy Supply D3020 Heat Generating Systems D3030 Cooling Generating Systems D3040 Distribution Systems D3050 Terminal & Package Units

		D3060 Controls & Instrumentation D3070 Systems Testing & Balancing D3090 Other HVAC Systems & Equipment
	D40 Fire Protection	D4010 Sprinklers D4020 Standpipes D4030 Fire Protection Specialties D4090 Other Fire Protection Systems
	D50 Electrical	D5010 Electrical Service & Distribution D5020 Lighting and Branch Wiring D5030 Communications & Security D5090 Other Electrical Systems
E EQUIPMENT & FURNISHINGS	E10 Equipment	E1010 Commercial Equipment E1020 Institutional Equipment E1030 Vehicular Equipment E1090 Other Equipment
	E20 Furnishings	E2010 Fixed Furnishings E2020 Movable Furnishings
F SPECIAL CONSTRUCTION & DEMOLITION	F10 Special Construction	F1010 Special Structures F1020 Integrated Construction F1030 Special Construction Systems F1040 Special Facilities F1050 Special Controls and Instrumentation
	F20 Selective Building Demolition	F2010 Building Elements Demolition F2020 Hazardous Components Abatement

construction, operations, and disposal (Charette, et al., 1999). “Benefits of UNIFORMAT II include providing a standardized format for collecting and analyzing historical data to use in estimating and budgeting future projects; providing a checklist for the cost estimation process as well as the creativity phase of the value engineering job plan;

providing a basis for training in cost estimation; facilitating communications among members of a project team regarding the scope of work and costs in each discipline; and establishing a database for automated cost estimating" (Charette, et al., 1999). In this thesis Uniformat II has been used as the standard to categorize the building elements. Table 2-3 shows the Uniformat proposed orderings.

RSMeans data is an estimation source which helps calculate the costs of construction prior to beginning construction. The database is used for a wide variety of construction types and can estimate based on overall materials, square footage and location. It can be used at almost any stage of cost planning but will become more accurate as the project progresses. RSMeans is the most commonly used estimation reference system and has become critical for the performance of Cost engineering (Markstein, et al., 2013). Reed Construction Data, which publishes RSMeans, was founded in 1975. RSMeans provides cost data based on different categories such as Uniformat II and Omni class.

Traditional technologies of CAD and generic 3D models have geometric inherent which is one of the properties of building entities. BIM capabilities are extended beyond the previous technologies so the geometry is served as the primary interface to interact with a building database in BIM (Sabol, 2008).

Building information models track information on all of the components that comprise a building, and can range from the very generic to the fully detailed. Figure 2-7 shows the difference of CAD versus BIM elements definitions.

Cost has been added as the 4^{th} dimension in the designed model. Benefits of 4D Cost model can be summerized as below:

- The possibility to develop project cost in different phases from conceptual to detailed design in one single document.
- Allow estimate with precise model-based takeoff quantities.
- Provide the visual capabilities for cost items.

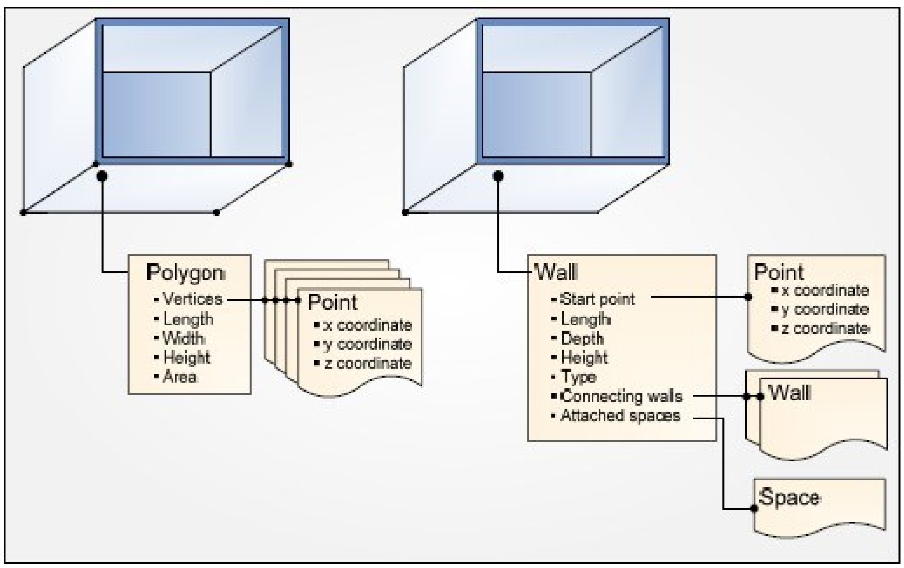


Figure 2-7-CAD vs. BIM - (Sabol, 2008)

2.4 Multi-criteria Decision-Making Analysis (MCDA)

The process of making a decision is decomposition and synthesis. Thinking is identifying objects and ideas; Identifying is decomposing the complexity we face; Then is to fine the relation among the identified objects and synthesize them (Saaty, 1980). Decisions are derived from the comparison of different points of views; some correspond with a certain decision and some against that. This clarifies the inherent of the decision making which is based on the plurality of points of view which cannot be defined as single criteria.

Therefore, for the last thirty years, a new approach for decision problems has come to the attention of researchers and practitioners. MCDA intuition is closely related to the way humans have always made decisions; thus although there is a wide range of techniques and methods in this domain, the basic elements of decision making are very simple: alternatives, solutions and sequence of actions. With the ingredients given, MCDA helps decision maker mainly regarding choosing, ranking and sorting alternatives (Figueria, et al., 2005). This theory is used for modeling the unstructured problems in economics, social and management science (Saaty, 1980).

Decision making is identifying and choosing alternatives based on decision makers' preferences. Making a decision is when there are alternatives to be considered and the decision maker prefers to have a large number of alternatives as possible. Moreover, the alternative which is selected should be the one that best meet the objectives and desired values (Harris, Robert, 2012).

According to Baker (2001) decision making should start with the agreement between decision makers and stakeholder on the definition of the problem, requirements, goals and criteria. Then it can proceed to a general decision making process following the steps indicate below (Baker, et al., 2001):

- Step 1. Define the problem

This step aims to clarify the situation; A one sentence (problem statement) that illustrates the current condition and the desired condition.

- Step 2. Determine requirements

"Requirements are conditions that any acceptable solution to the problem must meet" (Baker, et al., 2001). Requirements are the necessity not the sufficiency.

- Step 3. Establish goals

Goals are beyond the minimum essentials and requirements.

- Step 4. Identify alternatives

Alternatives are the possibilities for changing the condition from the existing one to the desired one.

- Step 5. Define criteria

Criteria should be defined according to the goal. Goals are represented in the form of criteria. These criteria should be discriminating since it is a measurement for the alternatives. In other words, alternatives are valuated based on the defined criteria. Criteria can be organized to the groups like a tree structure like: criteria, subcriteria, sub-subcriteria.

- Step 6. Select a decision making tool

Several tools are proposed for solving a decision problem which is a task that needs efforts. It depends on various factors such as the complexity of the problem or the objectives of decision maker.

- Step 7. Evaluate alternatives against criteria

Every acceptable method of decision making evaluates alternatives against criteria. The assessment may be objective (factual), considering some commonly scale of measurement, e.g. money, or it might be subjective (judgmental), based on the subjective assessment of the evaluator.

- Step 8. Validate solutions against problem statement

The selected alternative needs to be validated against the requirements and objectives of the decision problem. There is a possibility that the method of decision making was misapplied. Some of the Multi Attribute Making Models are described in the following pages.

2.4.1 MCDA Methods

2.4.1.1 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process is the most used tool in Multiple Criteria Decision Making. A large number of valuable researches have been published based on the theory of AHP in various fields such as planning, selecting the best alternative, resource allocations and optimization. Since the invention of the Analytic Hierarchy process, it has been of help to decision makers and researchers (Omkarprasad, et al., 2006). Choosing the factors that are effective in making a decision may be the most creative task. In AHP these factors are arranged in a hierarchic structure descending from an overall goal to criteria, subcriteria and then alternatives successively (Saaty, 1990).

Saaty developed the following steps for applying the AHP:

1. Define the problem and determine its goal and objective.

2. Construct the hierarchy from the top. The first level would be the objectives from the viewpoint of a decision-maker. The second level is the intermediate level which is the criteria on which subsequent levels depend. And the lowest level contains the list of alternatives. See Figure 2-8.

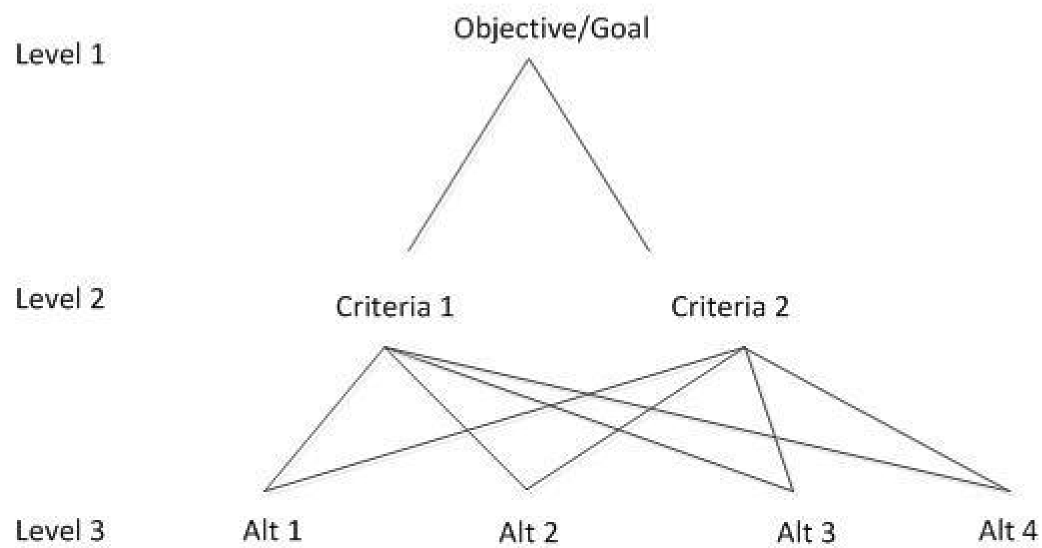


Figure 2-8- AHP Structure

3. Construct matrices for a set of pair-wise comparison with the size of $n*n$ in which n represents the number of the elements in the lower level along with one matrix for each element in the intermediate level. Table 2-4 shows the relative scale used for measurement.

The intensity scale of importance has been broken down into a scale of 1-9, the highest ratio corresponds to 9 and equal importance corresponds to 1 (Saaty, 1977).

The pair wise comparisons are done with respect of which element dominates the other.

4. To develop the matrix in level 3, *n(n-1)/2* judgments are required. Reciprocals are automatically assigned in each pair wise comparison.

Table 2-4-AHP Scale Of Measurement - (Saaty, 1977)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice.
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then j has the reciprocal value when compared with *i*	
Rationals	Rationals Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

5. Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weigh eigenvector entries corresponding to those in the next lower level of the hierarchy.

6. Once all the pair wise comparisons are done, the consistency is determined by using the eigenvalue, λ max, to calculate the consistency index. Consistency Ratios (CR) are used in order to measure the consistency of the judgments. Consistency Index, CI is calculated as: CI = (λ max-n)/ (n-1), where *n* is the matrix size. Consistency of the Judgment can be verified by comparing the consistency ratio (CR) of CI with its appropriate value in Table 2-5. The acceptable amount for CR is, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To have an acceptable consistent matrix, judgments should be revised and developed.

Table 2-5- Consistency Index- (Saaty, 1980)

Average random consistency (RI)										
Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

7. Steps 3 to 6 should be implemented for all levels in the hierarchy.

AHP pursues two main goals: Assigning weights to the predetermined criteria; prioritizing or ranking alternatives to identify the key elements (Cheng, et al., 2002). The priority vector is calculated by multiplying the *n* judgments of each row and taking the *nth* root, then normalizing the resulting numbers by dividing the sum of *nth* root column to every *n* judgment. This process is same for the alternatives comparing them one to another with respect to the criteria, in order to determine their relative value/importance for each criterion (Saaty, 1980). According to (Saaty, 1999-2000), the AHP calculations are easily doable in the spreadsheets and refer to (Edwards, et al., 1994) commercial software packages are available for the users in the market.

Converting subjective assessment of relative importance to a set of scores and goals is the main idea of the AHP approach (Fülöp, 2006). The extensive literature review of decision making reveals that most decision analysis models are quite subjective due to the subjective inherent of the decision making. However every decision maker uses steps to identify and tackle the problems and establish a framework to yield the optimum or near optimum solution. The number of steps accomplished throughout the decision making process should be selected wisely. Too few steps will not evaluate and address the problem properly and too man stages resulted in overanalyzing (Graham, 2012). Measurements in Paired comparisons in the AHP method are based on the observation of the relative importance of a property between two elements (Saaty, 1990).

Aside from converting the subjective assessment to the weights and score witch may be the most benefit of AHP, it has other advantages and disadvantages. Some of the advantages are:

- Allows the use of data, experience, insight and intuition in a logical fashion.

- Measure the inconsistency of the judgments. The AHP model provides the user with the capability to measure the degree of inconsistent judgments and introduce the acceptable tolerance level for the inconsistency (Graham, 2012).

In terms of the method disadvantages:

- If any interdependencies exist among the criteria it does not consider in the method.
- The use of subjective judgment which is subject to human error and biases
- The reversal rank is not consistent when one criterion is added or removed (Graham, 2012).

2.4.1.2 Comparing AHP with other multi-criteria decision-making method

ANP

The Analytic Network Process (ANP) is built upon the foundation of AHP. According to (Saaty, 1990), ANP introduces a general framework to address the decisions, considering the possibility of dependency between the elements within a level. That is to say, ANP can be used without defining the hierarchical level. ANP framework represents a coupling made up of two parts. First is a network of criteria and sub-criteria that control the relative interaction which is a control hierarchy; second is a network of influence among the elements and clusters.

"ANP is a decision making process tool that allows one to include all the factors and criteria, tangible and intangible which have bearing on making the best decision. The

Analytic Network Process allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay in human society, especially when risk and uncertainty are involved" (Saaty, 2001).

Simple Multi- Attribute Rating Technique (SMART)

Multi-Attribute Utility Theory (MAUT) is a quantitative comparison method. The method deals with the disparate measures. It amalgamates dissimilar measures along with individual priorities, into a cumulative preference. The foundation of MAUT is the use of utility functions. Utility functions are functions that transform unlike criteria to one common scale (0 to 1) which is known as the multi attribute "utility". Alternatives' raw data which are objectives and the analysts' opinion are converted to the utility score as soon as the utility functions are created (Edwards, et al., 1994). When quantitative data are available for every alternative, utility function will be used for better estimates of the alternative performance.

A good sample of MAUT method is the Simple Multi Attribute Rating Technique (SMART). This method utilizes simple utility relationships. It generally uses five, seven, and ten point scale. In case the data does not distinguish effectively the SMART methodology allows the use of less scale range. When actual numerical data are not available, subjective cognitive are replaced and documented in the final output (Goodwin, et al., 2004).

2.4.1.3 Sensitivity analysis

Values related to multi-attribute decision models are often subjective. There might be uncertainties in the weights of the criteria and the scoring values of the alternatives against the subjective (judgmental) criteria. The question is that how the decision model reflects the changes of some input parameters in the final ranking or the ranking values of the alternatives? (Fülöp, 2006)

When the variable is the value of the weight of a single criterion, the case is very simple. In terms of additive multi-attribute models, the ranking values of the alternatives follow a simple linear function of that variable and the sensitivity analysis can be applied using different graphical tools (Forman, et al., 2001). Regarding a wide class of multi-attribute decision models the stability intervals or regions for the weights of different criteria should be determined (Mareschal, 1988). There are also other models available that deals with the more complex sensitivity analysis (Fülöp, 2006).

2.4.2 Benefits of AHP/ANP

Comparative study of AHP and ANP in multi-criteria decision shows some of the benefits of using these methodological approaches:

1. As compared to other MCDM approaches, AHP/ANP is not proportionately complicated, thus this can be of help to improve management understanding and transparency of the modeling technique.

2. They have the ability to mix quantitative and qualitative factors into a decision.

3. AHP/ANP use a hierarchical structuring of the factors involved. The hierarchical structuring is a natural problem-solving paradigm in case of complexity.

4. AHP has proved to be valid from the decision makers' point of view as well in recent empirical studies.

5. AHP/ANP is a technique that can prove valuable in helping multiple parties (stakeholders) arrive at an agreeable solution because of its structure. (Taslicali, et al., 2006).

2.5 Criteria Development

Criterion as defined by Roy (1985) is “a "tool" allows comparing alternatives according to a particular "significance axis" or a "point of view"”. More precisely, a criterion is a real-valued function on a set of alternatives, such that it appears meaningful to compare the two alternatives according to a particular point of view (Bouyssou, 1990).

“In case of mono-criterion approach, the analyst builds a unique criterion reflecting all the relevant aspects of the problem. The comparisons that are deduced from that criterion are to be considered as preferences taking all the relevant points of view into account. In terms of multiple criteria approach, the analyst seeks to build several criteria using several points of view. These points of view represent the different axes” (Bouyssou, 1990). Decision makers will justify, transform and argue the criteria preferences throughout the decision making process. In other words a criterion is a model allowing establishing a preference relation among alternatives.

2.5.1 Criteria Specifications

According to Baker (2001), criteria should have exact specifications:

- Be able to discriminate among the alternatives and to provide the opportunity to compare performance of the alternatives.
- To be complete to embrace all goals.
- Be operational and meaningful.
- Avoid redundancy.
- Control the number (Baker, et al., 2001).

2.5.2 Defining Criteria for VE

Value engineering is a problem solving technique that utilizes quantitative methods and knowledge based decisions to improve owners' job satisfaction and help reduce unnecessary cost. A critical phase in the application of value engineering is the evaluation of generated alternatives based on the defined criteria for that purpose. To do so a multi-attribute decision making environment should be provided as well as criteria that proved to be effective in the decision making procedure. These criteria are not fixed and can be changed based on the each user preference.

"The main function of value analysis is to identify each element of function provided by each element of cost" (Miles, 1972). The purpose of each expenditure, no matter it is for hardware, the team work, a procedure, or so forth, is to accomplish a function. It is necessary to clarify the definition of function. Functions are divided into two types. Either or both affect the decision makers' selection.

To be more beneficial functions are named using a verb and noun that have measurable parameters, in case that was possible. This provides the opportunity to predetermine approximate worth and appropriate cost of the functions. More details can be found in (Miles, 1972). After functions are identified, clarified, understood, and named, they can be classified as either *basic* or *secondary* functions. Basic functions are those functions for which the customers need device or service. Secondary functions are those functions allow the designer's to choose different means to accomplish the basic functions. "For instance, the basic function of a refrigerator is to preserve food. If a refrigerator has electric contacts that open and close to regulate its cycle of operation, then the function of mounting and protecting the contacts is required. If the refrigerator has solid-state control equipment with no moving parts to control its operating cycle, then a very different function-different in design and different in cost-may be needed to cause or allow it to accomplish its task" (Miles, 1972). Selection of the secondary function is based on the user and there is no universal method to add or eliminate the secondary functions. The percentage of cost spends on the secondary function is relatively unrelated to the basic functions.

The cost of alternatives is the question that should be properly and objectively addressed; however it worth noting if cost be considered as a single criterion in value engineering; it only makes sense in the requisite sense. Results of group investigation using experienced, multi-disciplinary teams, illustrate that value and economy of a project can be improved by generating alternatives with different design concepts, materials, and methods without compromising the function and value objectives of the client (Miles, 1972).

A client selects a product or uses a service to accomplish certain functions. These criteria are exclusively *use* and *aesthetic*. Once the concept, which is accomplishing the basic function, is done, the choice of *materials, shapes, assemblies, methods,* functions, *tolerances*, etc. will be taken into account. Appropriate cost can a1so be lost in this work area depend on the client preferences.

Counting aesthetic as one of the criteria follows different patterns due to subjective nature of the aesthetic. Specific functions under the aesthetic category often suggest some better solutions. Some typical names are: Provide appearance, Provide shape, Provide color, Provide features, Provide convenience, Reduce noise, Reduce size, Reduce thickness, Reduce time required, Reduce skill required. Sometimes costs spend on the aesthetic area bring the best value. It depends entirely on what the customer decides and chooses and is willing to pay for.

Value analysis studies have shown that appearance-design area brings great benefits. On the other hand, technical people focus on the development of *performance*. It is a rather widespread belief at improved appearance and performance requires increased cost which is barely the case. Due to the inherent philosophy of value engineering, identifying and removing unnecessary cost, should improve the value without reducing in the slightest degree quality, safety, life, reliability, dependability, and the features and attractiveness that the customer wants (Miles, 1972).

There is no direct relation between cost and quality. Good quality means the selection of the best answers to the question of how to use *materials, processes, parts*, and *human efforts* to accomplish these functions. "Constructability" is the term used in the United States (US), where "Build ability" is the term rather use in Europe. Constructability is defined as a measure of the ease or expediency with which a facility can be constructed (Anderson, et al., 1999).

The benefits of improved constructability have direct impact on the time, cost, quality and safety performance of a project, along with other intangible benefits. According to Hijazi (2009) it was found that quantifying assessment of designs; constructability review; and implementation of constructability programmers, are the three most commonly employed approaches in measuring the improving constructability (Hijazi, 2009).

Un-functional Cost in the Construction Industry

The industry is surrounded by obsolete codes and by differing codes. Examples of unchanged codes through twenty to thirty years are far too common.

- Obsolete design details are repeated from job to job
- Materials that bring no user function (either use or aesthetic) are often used and new functional materials are not used
- Practices from the past are followed
- Habits from the past enter the design, contracting, and construction

Businesses involve in the construction jobs are architects and engineers, contractors and owners. Architect and engineer are supposed to produce a good competitive design from available materials and skills without uncertainties while guarantee minimum design cost. Using newer materials and/ or approaches needs time and expense searching and testing. Moreover, the time, expense, and uncertainty involved in attempting to communicate with and convince the owner should also be considered. Lastly, the contractor may have some difficulties in finding the equipment and skills needed to utilize the new approach in the construction phase. Present methods of material selection involve the architect-engineer, w-ho selects materials that conform to the design criteria of the owner. The architect-engineer is responsible for defining the materials that most suit the *economy, function*, and *maintenance*.

Contractor's value analysis often determines that investment in additional materials, even better than specified, may result in a better product installed at a lower overall cost (O'Brein, 1976). The owner relies upon the architects and engineers to design the building for him that meets his needs in the most economical way while provide the use and aesthetic functions. He can always welcome the use of new functional products and processes, but he must lay responsibility on architects and engineers.

In the final analysis, perhaps value engineering is no more than the formal application of standard problem solving to building design. However, there is evidence that such an approach can indeed produce better solutions considering the client desired criteria.

2.6 Summary

From reviewing literatures it was understood that despite of current literatures contributions, certain areas still need more improvement. Generally, selection of the most suitable (near optimum) alternative based on multi-attributed criteria has always been an issue for design professionals and owners. Value engineering will be applied to these cases to present clients with the alternative that guarantees maximum value. Limited work has been carried out in the application of value engineering. The absence of models that can be of help to VE team members to choose the optimum alternative, has long been felt; As well as a creative means for the value engineering team members to enhance their ability to generate more innovative alternatives.

According to Miles (1972), Focusing on time, cost and other qualitative aspects of a project in value engineering analysis means that decision making regarding qualitative aspects should be improved. Due to subjective inherent of the quality, decision making regarding quality is not negotiable. Existing resources has not been fully used hence there has been a lack of effort in developing and evaluating alternatives. Another issue is the absence of effective communication among project parties that mainly resulted in unnecessary costs.

The thesis proposes an automated integrated model in support of value analysis. The model provides the user and value engineering team members with visualization capabilities. The visualization can be of help both in the application of the creative phase of the VE job plan and in the evaluation of the generated alternatives. The proposed model provides an automated decision making environment for users to evaluate the generated alternatives using Analytic Hierarchy Process. Using AHP will convert the subjective assessment of relative importance to a set of scores. Applying AHP to evaluate different alternatives is a time consuming process and rather confusing especially as the number of the competing alternatives and wanted criteria are increasing. The model automates this procedure of evaluating alternatives. And integrating that with BIM model using Autodesk Product; Revit 2013 software would provide visualization capabilities for the users. 4D modeling of the building and its components is done in BIM model; also using the model, the cost estimating of the project alternatives are generated subsequently where cost is the 4th dimension added to the model.

3D models are much closer to everyday reality, they facilitate communication among the actors in a project: owner, architects and their consultants, contractors, fabricators, and potentially, operators (Eastman, et al., 2011) hence it can lessen the unnecessary cost causes by the lack of communications. Using BIM also brings other benefits to the projects like: providing 3D Interface, Automated 2D drawing engine, Geometry change management engine, Clash detection engine, Automated schedule of material engine, Automated material take-off engine, IFC compatibility and 4D modeling.

Although Value engineering can be applied at any stage of the project life cycle; however it has been proved to be beneficial if applied during the early stage of the project (O'Brein, 1976). The designed model has the potential to be applied at any stage of the project.

In the final analysis, perhaps value engineering is no more than the formal application of standard problem solving to building design. However the prototype decision support model will enhance the application of value engineering. It integrates through its database projects' BIM models for automated data extraction and to support visualization, RSMeans for cost estimating data and a coded application of the AHP for assisting users in the evaluation and process and then ranking competing alternatives. The model is flexible; allowing users to specify different evaluation criteria for each group of project components. This feature minimizes data entry and speed up data processing.

Chapter Three: Research Methodology

3.1 General

As represented in the previous chapter, application of the Value engineering is essential for capital projects which require commitments of considerably large resources. However a lot has yet to be done in the application of value engineering. Value engineering will help in developing better understanding and appreciation of the project scope of work and in reducing unnecessary cost without impacting the required functions of project components being considered. The absence of models that improve implementation of value engineering has long been felt. Intellectual work should be done to enhance the capabilities of value engineering to choose the optimum alternative and to be able generate more innovative alternatives with respect to desired functions.

The model proposes in this research can be of help to value engineering team members, design professionals and owners and stakeholders. Selection of the most suitable (near optimum) alternative based on multi-attributed criteria has always been an issue for design professionals and owners. There is no universal answer to this problem since the selection criteria and their relative weights vary from one project to another, in order to satisfy owners' construction needs and project targeted objectives.

The thesis introduces an automated model to evaluate and compare different alternatives of a project based on the defined multi attributed criteria as well as integrate that model with visualization capabilities. The model suggests advanced means for VE team members to generate alternatives wisely and to assist designers and stakeholders in making related decisions. A set of tools and techniques has been used in this decision making model in order to assess several alternatives and support designers/owners to critique their choices, thus choose the near optimum one.

This chapter outlines the methodology implemented in making the automated model. A prototype decision support model has been programmed in Microsoft Visual studio. It uses a coded application of the AHP to help users in the evaluation of competing alternatives. The project BIM model using an Autodesk product; Revit 2013 has been used to support visualization and to extract data for cost estimating of the project. 4D modeling of the building and its components is done in BIM model. The model then uses RSMean as the cost database. Figure 3-1 shows the methodology procedure.

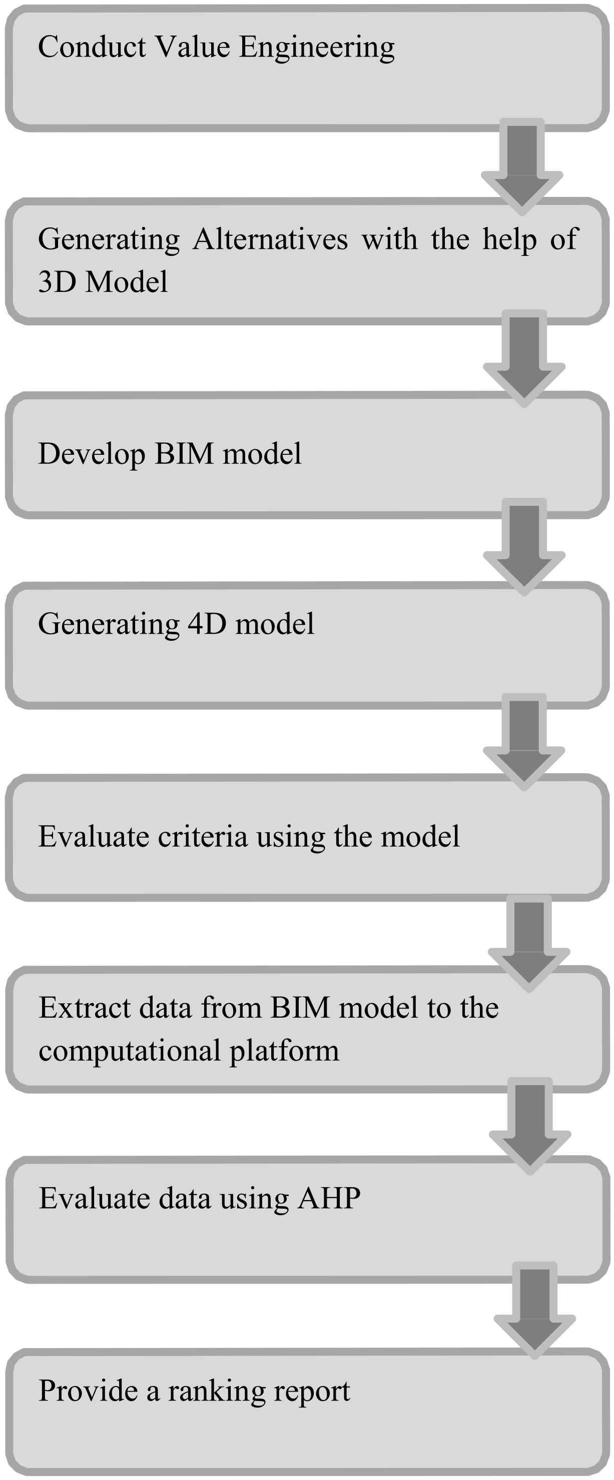


Figure 3-1-Methodology overview

3.2 Methodology Implementation Procedure

The main objective of this research is to propose an integrated model in support of value engineering. The model provides users with an automated and comprehensive computational platform that considers a wide range of aspects for evaluation and selection of near optimum alternatives that satisfy the owners' requirements.

The value engineering analyzes the scope of the project to achieve the essential functions required without compromising the client objectives. This process consists of techniques, organized into a Job Plan which is composed of six key steps as explained in the literature review chapter 2-2-1. A critical phase in the application of value engineering is the evaluation of generated alternatives based on predefined criteria. For that purpose, a prototype model has been designed and developed to help the VE team to evaluate and rank different design alternatives of project components using multi-attributed criteria. The model integrates BIM to provide visualization capabilities to assist designers and stakeholders in making related decisions.

Aside from the 3D geometrical model, an automated 4D model in support of Value Engineering Analysis has been developed. The 4^{th} dimension is cost which is added to the developed model. The model integrates through its database projects' BIM models for automated data extraction and to support visualization, RSMeans for cost estimating data and a coded application of the AHP for assisting users in the evaluation and process and then ranking competing alternatives in an objective manner.

The proposed method assists members of value engineering teams to perform the evaluation process with relative ease and in a timely manner. Also to understand visually and numerically the consequences of any introduced change of the alternatives. A set of graphical user interfaces was designed to facilitate user interaction with the software by application of VS 2010.

The main process of the methodology is described in the sequences of steps.

The methodology has been summarized in the flowchart 3-2.

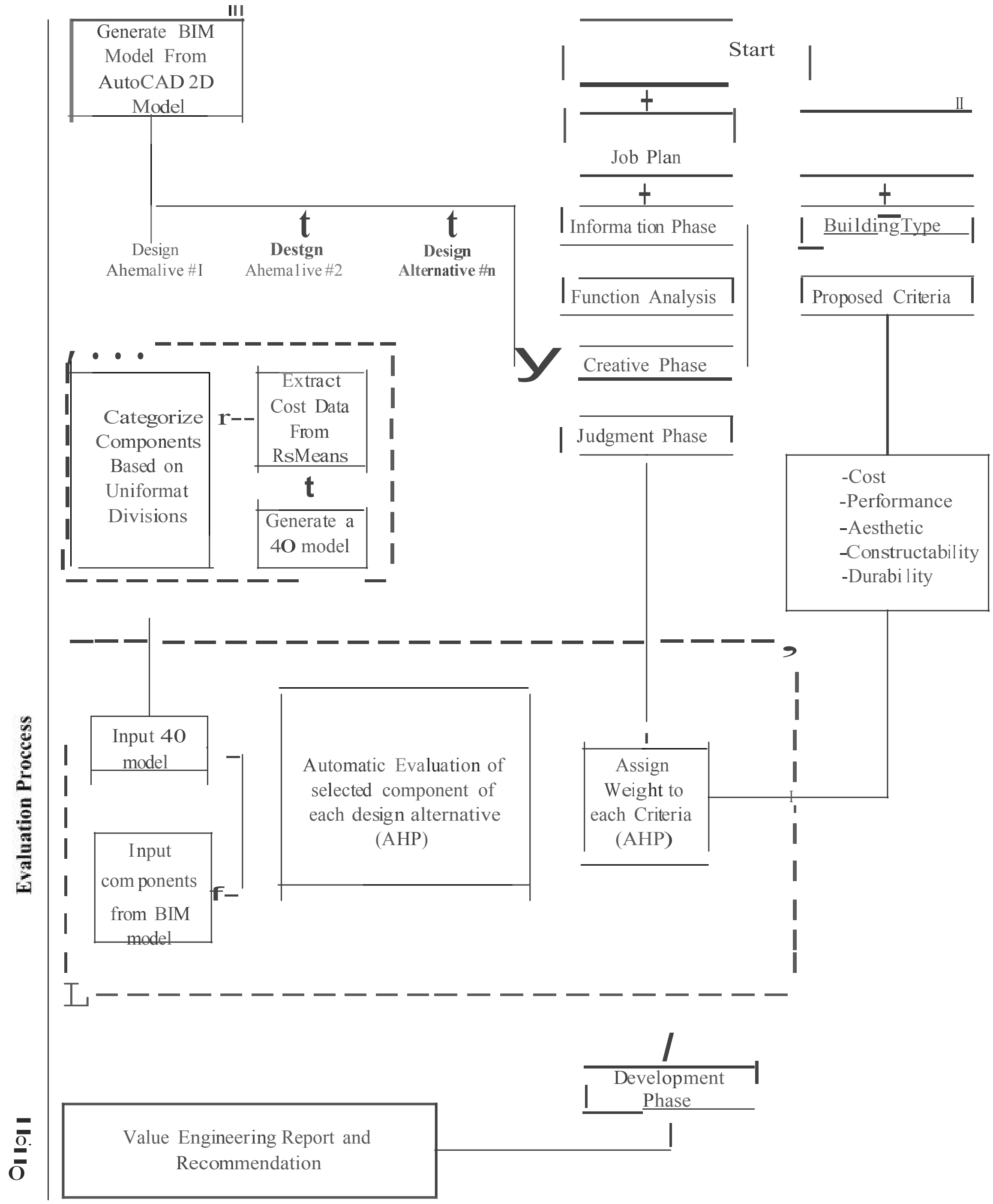


Figure 3-2-Methodology flowchart

3.2.1 Value Engineering Job Plan

The first step to implement the proposed method is to define the specifications of the project. Projects cannot be successful if the goals are not defined crystal clear in the early stage of the project. The process starts when the value engineering team is formed. Philosophy of the value analysis is to supply the human being with sufficient tools to accomplish their work in a timely manner. The standard of three-Stages of Pre-Workshop, Six-Phase Workshop Job Plan activities and Post-Workshop is explained extensively in the literature review chapter. When the pre-workshop is conducted, then the team starts the value engineering job plan.

First and second steps of the value engineering job plan, Information phase and Analysis phase, are to collect required facts, assumptions (beliefs) and information about the project. In order to define the project scope and clarify the basic functions, VE team members use function analysis. By using function analysis the efficiency of the functions could be improved and potential significant cost savings would be achieved. This step will focus on essential "function"; Functions would be evaluated, and a detailed problem setting would be provided afterwards. The team and the project stakeholders should identify and understand the project’s basic and secondary functions. Basic functions must be maintained; otherwise the intended study goals will not be accomplished.

Buildings are categorized into different types with generic criteria for each group. Design and construction of a building is highly influenced by the type and category of the building. For each general building type there are requirements and design specifications that need to be considered. There are resources available which explain the standards, technologies, issue and characteristic of every building type. Several factors should be taken into account in order to define a building type and then to determine the requisite criteria for that type as well as the sufficient conditions.

Despite the existence of some prerequisite criteria for each building type, these criteria are not consistent for every project. The criteria vary from owner to owner and from project to project. This fact evidences the reason that there is not a universal answer in the selection of an alternative for a building. In the first step of the proposed method, the user is supposed to define the characteristics of the building he considered to build. One project is successful indeed only if the goals and objectives of the project are defined early and clearly.

3.2.2 Criteria Development

Criteria development is related to the Information Phase and Functional Analysis Step of the value engineering Job Plan. By selecting the desired building type, the method proceeds to the selection of the criteria for each building type. Criteria considered for each building type play an important role in the last results of value engineering. Aside from the building type, selected criteria and their relative weight are the main reason that a single solution cannot answer the selection of an alternative for a building. Technical requirements and objectives of every building project are unique to the project type hence the criteria selection of every project varies from others.

Criteria considered for every project is dynamic and can be specified for different systems and subsystems. The difference of the criteria is directly related to the objective of the project and preferences of the owners, stakeholders and designers. This needs gathering of all the parties involved in the project. Every design discipline is specific regarding skills, professional standards and issues that drive how they operate in the building process. To yield multiple benefits and for the project to fulfill all its requirements, various stakeholders and disciplines should coordinate and interact in the early stage of the project (Conway, 2010). 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. Sometimes individuals who have relevant expertise; but are not directly involved with the project are added to provide a different point of view (SAVE, 2007).

In this step the criteria should be defined. The method will propose a list of criteria for each building type derived from the literatures reviewed throughout the chapter two. The user can use the suggested criteria or use his/her preferred criteria. The relative weight of each criterion should also be determined based on the user's preference. Section 3.2.5 explains this evaluation procedure thoroughly.

3.2.3 Alternatives Generation

This section is pertinent to Speculation Phase of value engineering Job Plan. In this step value engineering team tries to generate various alternative and ideas with focus on the defined criteria. The VE team provides alternatives within the requisite area of the project. 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. No matter how experts are the value engineering team, there are some alternatives that always remain concealed.

The proposed method in this thesis tries to assist value engineering in generating creative alternatives. To accomplish the clients' desired functions, the creative concepts and essential knowledge should be integrated to provide customers with several function alternatives. In order to accelerate the creative activities firm action is needed. That is to say, every part of the VE job plan should be effectively used to achieve a high degree of value.

3.2.4 BIM models Development

The methodology is to produce an automated model in support of VE. For that purpose the BIM model of the project's alternatives should be generated. 3D BIM models provide visualization capabilities for users. 3D views allow the VE team members to have a preview of the project prior to construction. That is to say, it provides a clear picture of the project; this will activate the imagination potential of the VE team members to be able to produce more innovative alternatives. In other words, having a clear, vivid imagination of the project, the process of generating creative alternative is eased by having the 3D views of the model available.

In the BIM models, specifications and properties of the components are embedded in the model, so a wide range of components with different materials is available for the VE team to examine alternate specifications for different components of the project with respect to defined criteria.

4D modeling of the project is also done in the BIM model. The 4^{th} dimension that has been added to the model is cost. The BIM models provide quantity takeoff and schedule of components at every design stage of the project. So the cost estimate of each alternative can be calculated at every stage. By this opportunity, the cost of the alternatives generated, can be estimated at any stage through its producing process. The VE team will have a clear understanding about the consequences of the changes they make on every alternative so they can generate them wisely.

The model can also be used in the architectural design. Integration of 3D visualization along with the 4D modeling can be beneficial during the conceptual phase. The integration of 3D and 4D model with a selection of material while you have the rough estimate of the alternative produced can be of help to the VE team in the speculation phase of the job plan and will assist them to be able to produce numbers of innovative alternatives.

3.2.5 Criteria Assessment, Automated Alternatives Evaluation

Evaluation Phase of value engineering Job Plan is explained in this section. The main contribution of the thesis would be in the evaluation phase of the value engineering job plan. The method proposes an integrated model to assist owners, professional designers and members of VE teams to make a value driven decision among generated alternatives.

Analytic Hierarchy Process (AHP) is a tool for Multiple Criteria Decision Making. AHP technique is applied in two steps. First the *criteria* are evaluated against each other to find their relative *weight,* and then the *alternatives* are assessed against each criterion in order to generate the *score* of each alternative. The criteria's weight is defined based on users' preferences.

Pairwise comparison is also performed for assessment of the alternatives being considered; this can be a time consuming process in the application of the AHP; as users are required to answer each comparison twice in order to check the consistency of the answers provided.

The thesis proposes a model to ease the process of pairwise comparison for evaluating criteria to find their relative weight and automate the process of comparing alternatives with respect to defined criteria in order to find the relative score of them and consequently provide a report for the VE team. Aside from the convenience that model provides, automation of this step guaranties consistency in the evaluation process and is expected to save time.

The model proposed in the thesis is a computational platform that by using the AHP technique algorithm ranks different alternatives and generate a report for VE team. As it has been discussed earlier in this thesis, the BIM model has the ability to produce schedules of components and a list of material. This quantity takeoff is one of the inputs of the computational platform. Alternatives are evaluated automatically in the computational platform. In this process, data pertinent to the project components being evaluated are generated directly from the project BIM model.

The items are ordered based on Uniformat II classification in the Revit model so the assembly code of the Uniformat is embedded in the report generated by the Revit. RSMeans provides cost data in the Omni class divisions and Uniformat divisions. In this research the cost data based on Uniformat divisions is used. Note that BIM model and cost data should follow same classification. See Figure 3-3.

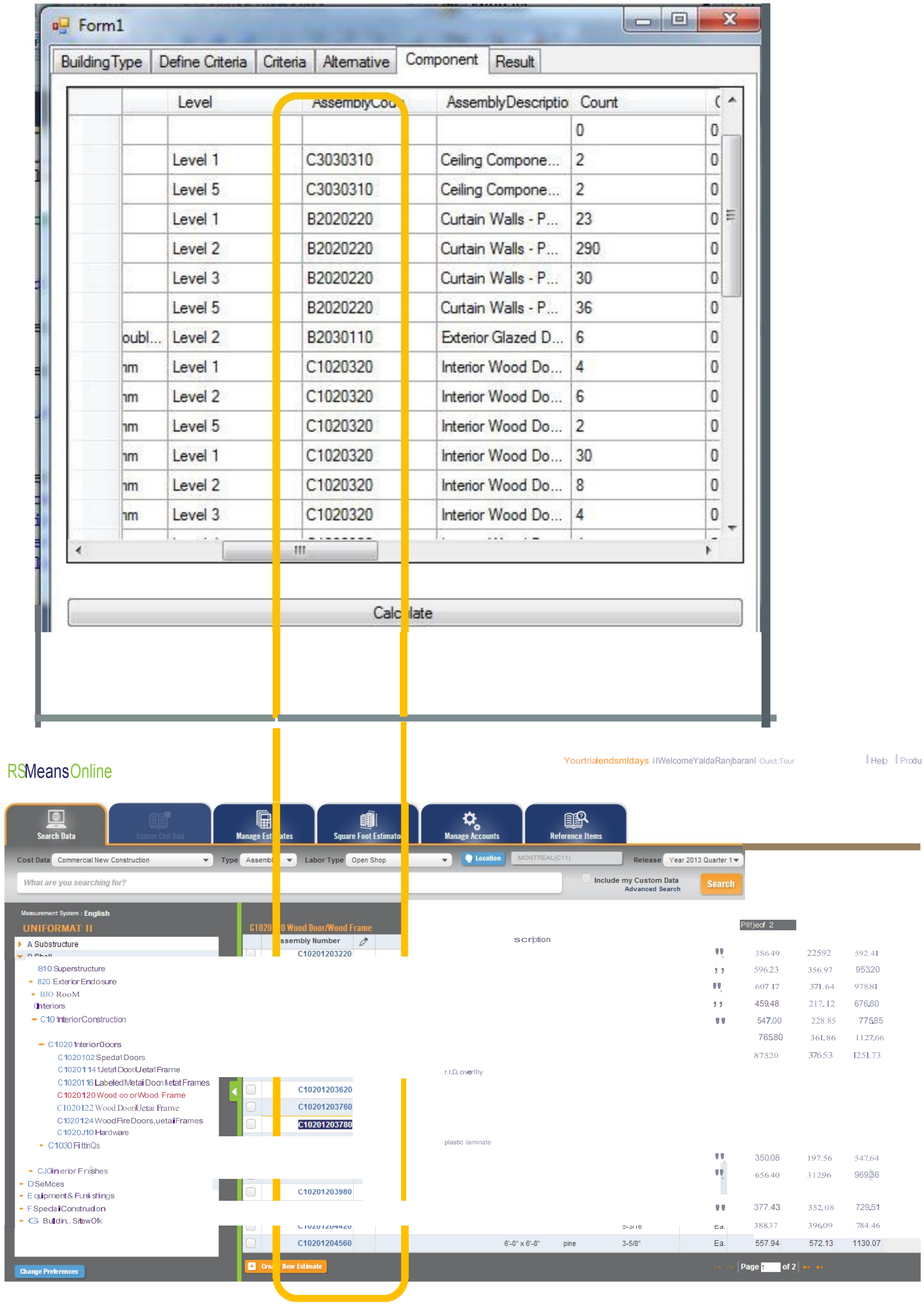


Figure 3-3-Rsmeans Classification Match With Components Classification

The steps involved in the evaluation phase of the methodology can be summarized as below:

- The user evaluates criteria to find out the relative weight of each criterion, the user enters his/her evaluation in the interface designed for the model. See chapter four
- The alternatives BIM model is generated
- Data extracted from BIM model are classified based on Uniformat divisions
- The extracted data are entered into the model to evaluate alternatives against each criterion
- RSMeans Cost Data are linked to the model
- RSMeans data are matched with the extracted data from Revit and cost estimate of the alternative is generated.
- The score of each alternative regarding cost would be determined depends on the cost weight
- AHP algorithm ranks the alternatives and a report is generated

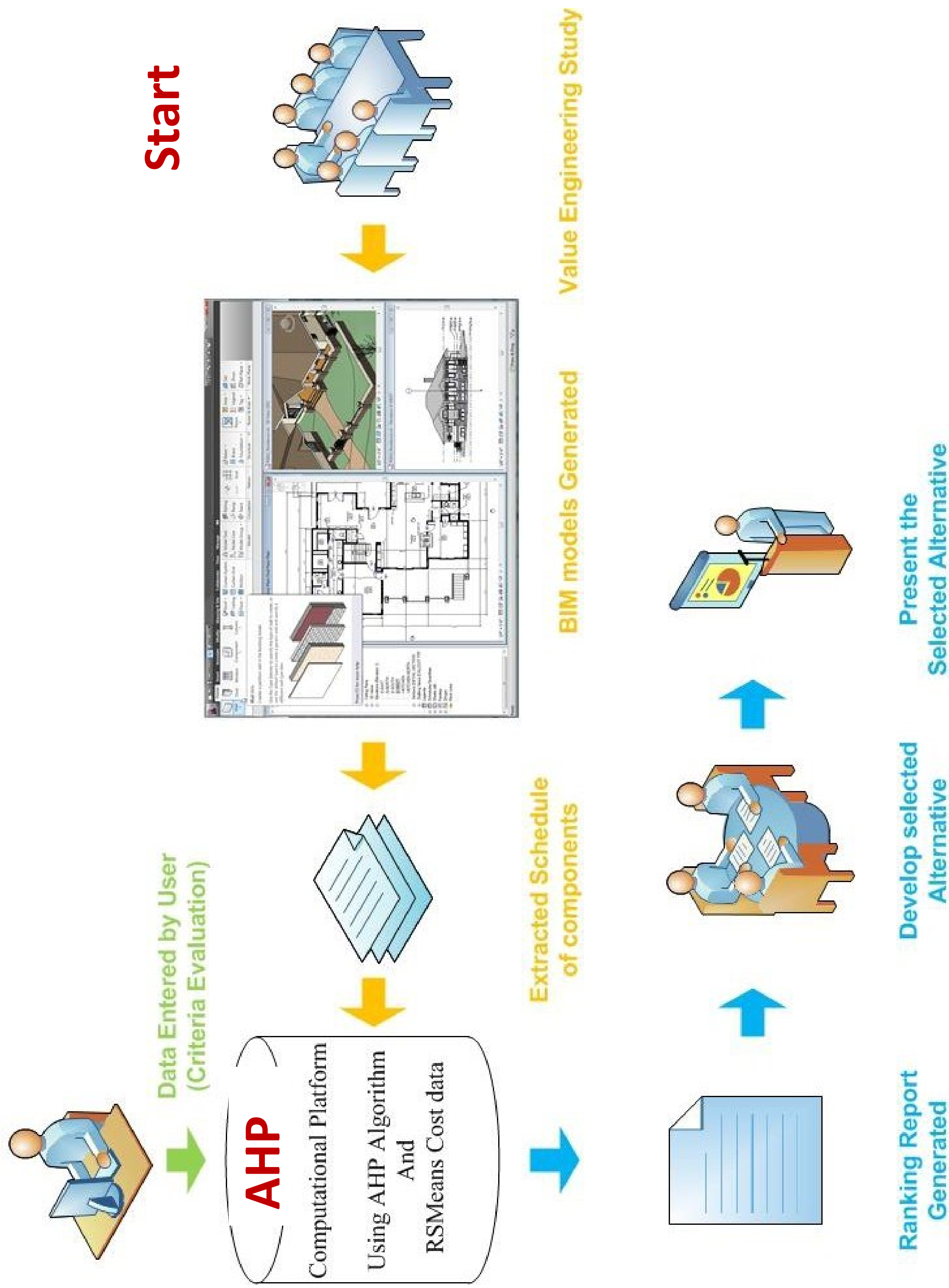


Figure 3-4-Research Methodology

As it has been mentioned in the literature review chapter, AHP model evaluates each alternative against all defined criteria. This assessment is straight forward and certain regarding cost since it is a numerical calculation. The cost of every alternative will be calculated and the final cost of each alternative which is a figure, will be compared against each other.

However the evaluation of the alternatives versus other criteria is a qualitative assessment. To asses selected components of the alternatives against other criteria, the qualitative assessment should be converted to the quantitative assessment. For every component versus the criteria, there is a choice of three values; Low, Medium and High. See Figure 3-5.

Wall Schedule

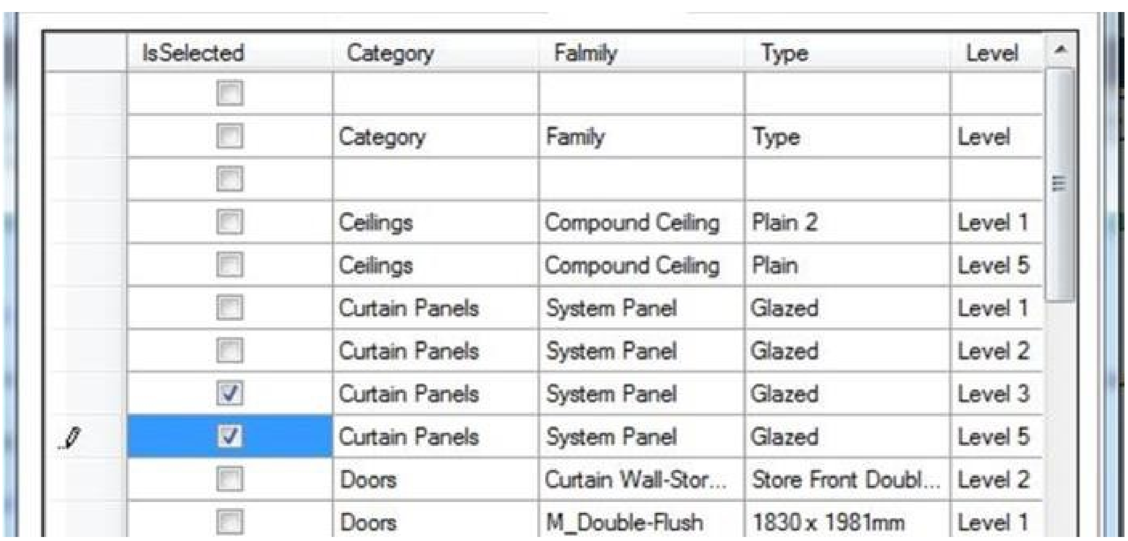
W	Assembly Co	Assembly Description	Coun	C	Aesthetic	Performance	Constructabil	Durability
2	B2010140	Ext. Wall - CMU	22		High	Low	High	High
9	B2010158	Ext. Wall - Brick Veneer w/ Stud	62		Low	High	Medium	Low
4	B2010200	Parapets	25		Meium	Low	Medium	Medium
3	A1010220	Foundation Walls - CMU	3		NA	Medium	High	High
1	C1010120	Partitions - CMU	311		High	Low	High	Medium
1	C1010145	Partitions - Drywall w/ Metal Stud	1		High	Low	High	Medium
5	C1010145	Partitions - Drywall w/ Metal Stud	22		High	Low	High	Low
3	A1010210	Foundation Walls - CIP	43		NA	High	High	High
6	A1010210	Foundation Walls - CIP	11		NA	High	High	High
	B2020200	Curtain Walls	37		High	Medium	Low	Medium

Figure 3-5-Screen Shot Of Revit Model Wall Schedule

The intensity scale of importance in AHP technique as Saaty has defined has been broken down into a scale of 1-9, the highest ratio corresponds to 9 and equal importance corresponds to 1. The associated value considered for Low and Medium are 3 and 5 respectively and the numerical equivalent of High is 9. These equivalents are arbitrary and can be changed as a user preference.

For criteria other than cost, the BIM model assigns the value of the components of the alternatives by default. These values are assigned to the components based on the catalogues available in the market and the specifications advertised by the companies, as Low, Medium and High. The developer of the Revit model should be one of the VE team members or has the close communication with them, assigns values to the components. When the clients are using the model he/she can use the default values embedded in the model; otherwise the model gives the user the option to enter values for the selected component based on their own evaluation or judgment manually.

Generally value study focuses on improvement of a specific part of the whole project to conduct value analysis on. This can be any of the components of the building that VE team tries alternate material, shape or function to examine the best value. The fact that the components in the model are classified based on the Uniformat divisions simplify the selection of the components. The components can be selected either based on their classes or individual component can be taken into consideration. See Figure 3-6.



IsSelected	Category	Falmily	Type	Level
☐				
☐	Category	Family	Type	Level
☐				
☐	Ceilings	Compound Ceiling	Plain 2	Level 1
☐	Ceilings	Compound Ceiling	Plain	Level 5
☐	Curtain Panels	System Panel	Glazed	Level 1
☐	Curtain Panels	System Panel	Glazed	Level 2
☑	Curtain Panels	System Panel	Glazed	Level 3
☑	Curtain Panels	System Panel	Glazed	Level 5
☐	Doors	Curtain Wall-Stor...	Store Front Doubl...	Level 2
☐	Doors	M_Double-Flush	1830 x 1981mm	Level 1

Figure 3-6-Selection of the Components in the Revit Model

3.2.6 Alternative development and Sensitivity Analysis

Development Phase of value engineering Job Plan is about alternative development and sensitivity analysis. The report generated in the previous step is analyzed here so the number of generated alternatives and ideas would be reduced, focusing on the value oriented solution that would meet the owners' preferred criteria (SAVE, 2007).

In this step sensitivity analysis is conducted, if needed, to understand how the decision model reflects the changes of some input parameters in the final ranking or the ranking values of the alternatives. Due to the uncertainties possibly exist in the decision making process sensitivity analysis can be carried out in the development phase of the value engineering. This development encompasses following points.

- Improvement of the generated report and conduct sensitivity analysis in case needed
- Description of the recommended alternative
- Providing a description of the specifications of the selected alternative
- Providing the cost estimate of the alternative selected for the project as well as a cost comparison with other alternatives
- Presenting the recommendation is along with a comparison of the original design method with the proposed change
- Provide data extraction, quantity takeoff and 3D model sketches

Present the developed model to the client

The final step in the application of the VE Study is the presentation of the selected alternative and provides the recommendations in the form of a written report. The presentation of results is made to the Client and Users. The recommendations encompass the rationale leads to the development of each alternative. A summary of key cost impacts is available at the time so that a decision can be made with awareness of the cost of the value. The accepted Value Management proposals will be implemented in the phase of construction.

In addition to the monetary benefits, a VE Workshop provides a valuable opportunity for key project participants to come together, then step aside and view the project from a different perspective. The VE process therefore produces the following benefits (Scott, 2010):

- Provide the opportunity to explore all possible alternatives
- Prepare presentation and supporting documentation
- Focus on the "value" and "function"
- Identifies and prioritizes Client's value objectives
- Clarify project objectives
- Implements accepted proposals into design
- Provides feedback on results of the study

3.3 Summary

The main objective of this research is to propose an automated model in support of value engineering. Value engineering is a function oriented systematic team approach to provide value which often focus on cost reduction; however other important criteria are also of paramount importance in the value equation. The method is for designers/owners to be able to evaluate and compare different alternatives of a project based on the defined multi attributed criteria as well as integrate that model with visualization capabilities to assist designers and stakeholders in making related decisions. A set of tools and techniques has been integrated in this decision making model in order to assess several alternatives and support designers/owners to critique their choices, thus choose the most optimum one.

The methodology is to develop a multi attributed decision environment using Analytic Hierarchy Process to evaluate competing alternatives; And to integrate that with the BIM model using Revit software to provide visualization capabilities and assist cost estimating of the project component being considered. The output which has been classified based on Uniformat division would be linked to the model. The model would rank the data and generate a report for the user. The report can always be tracked and modified using the automated model.

Chapter Four: Model Implementation

4.1 General

Value engineering is a function oriented problem solving approach to assure value required by the client. The selection of an alternative depends on the preferences of the owner and designer and there are multiple solutions to this problem vary from client to client. The best choice is the one that best suits the owner's considered criteria. This thesis aims to introduce an automated 4D model in support of Value Engineering Analysis. The models assist Value engineering team to generate creative alternatives and then select a value driven alternative among generated alternatives.

4D model of the project is prepared using the project BIM model. Aside from the 3D parametric model, the 4th dimension is cost in the developed model. The model integrates through its database projects' BIM models for automated data extraction and to support visualization, RSMeans for cost estimating data and a coded application of the Analytic Hierarchy Process (AHP) for assisting users in the evaluation, process and then ranking competing alternatives in an objective manner.

The proposed model introduced in the methodology has been programmed in Microsoft Visual Studio C# using a multi-attributed decision making environment, AHP to evaluate competing alternatives. User is required to respond to a pairwise comparison question for every pair of criteria to establish their relative weights based on the nine point scale.

Applying AHP to evaluate different alternatives is a time consuming process and rather confusing especially as the number of the competing alternatives and wanted criteria are increasing. The model automates this procedure of evaluating alternatives. And with integrating that with the BIM model using the Autodesk Product; Revit 2013 software would provide visualization capabilities for the users. 4D model of the building and its components is done in BIM model; also using the model, the cost estimating of the project alternatives is generated subsequently. If cost is included in the owner's defined criteria, relative weight would be assigned to that and it will be considered in the evaluation procedure.

4.2 Automated Model Application

The proposed method assists members of value engineering teams to perform the evaluation process with relative ease and in a timely manner. Also to understand visually and numerically the consequences of any introduced change. The steps that illustrate the main process of the model are described in the following steps.

1. Buildings are categorized into different types with generic criteria for each group. Type and category of the building affect the design and construction of a building. Each general building type requires its own specifications that distinguish that group from other building types.

   To determine the requisite criteria and sufficient condition of a building type several factors should be taken into account. Based on the literatures studied, the model proposes some building type in the first step. The user can add his/her considered building type in the model or edit the building type existed on the model. Figure 4-1 shows the model interface.

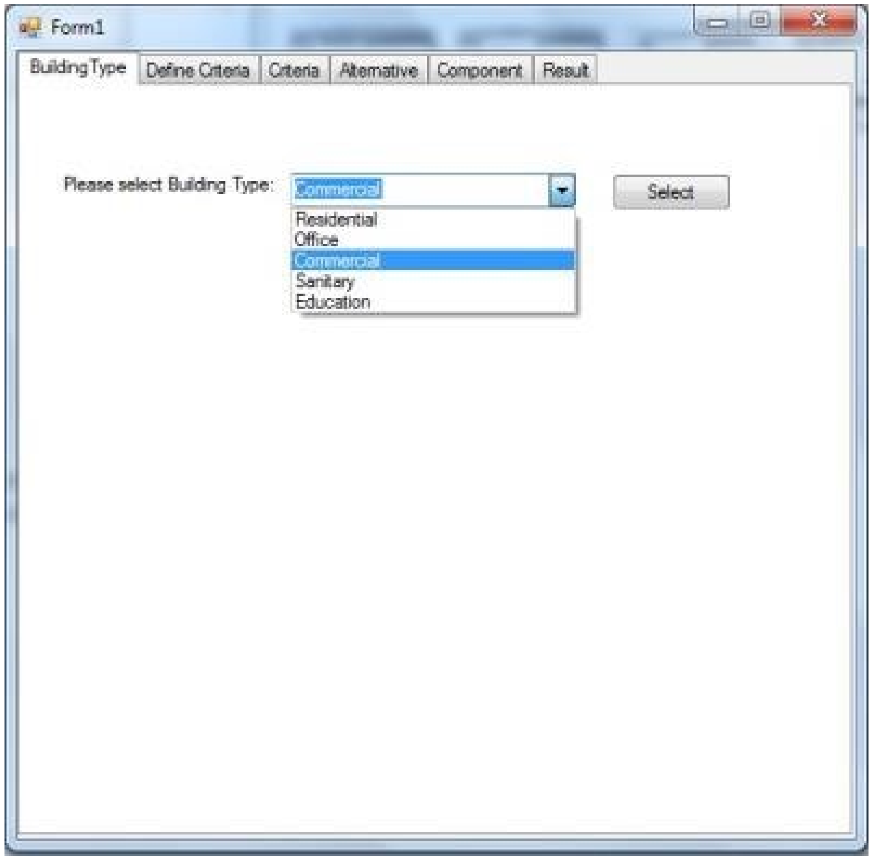


Figure 4-1-Model Interface-Select Building Type

2. Once the building type is selected, the criteria required for the building type should be defined. Objectives and specifications of every building type are unique to that type hence the criteria selection of every project varies from others. Aside from the technical requirements of the building type, preferences of every client, owner, stakeholder and designer vary from others.

   To yield multiple benefits and for the project to fulfill all its requirements, clients' desired criteria should be taken into account. For every building type, the model proposes predefined criteria. These criteria can always be edited and revised by addition and/or deletion, as its suit users. In this step, the user is asked to define his considered criteria, making use of those stored in the model. See Figure 4-2.

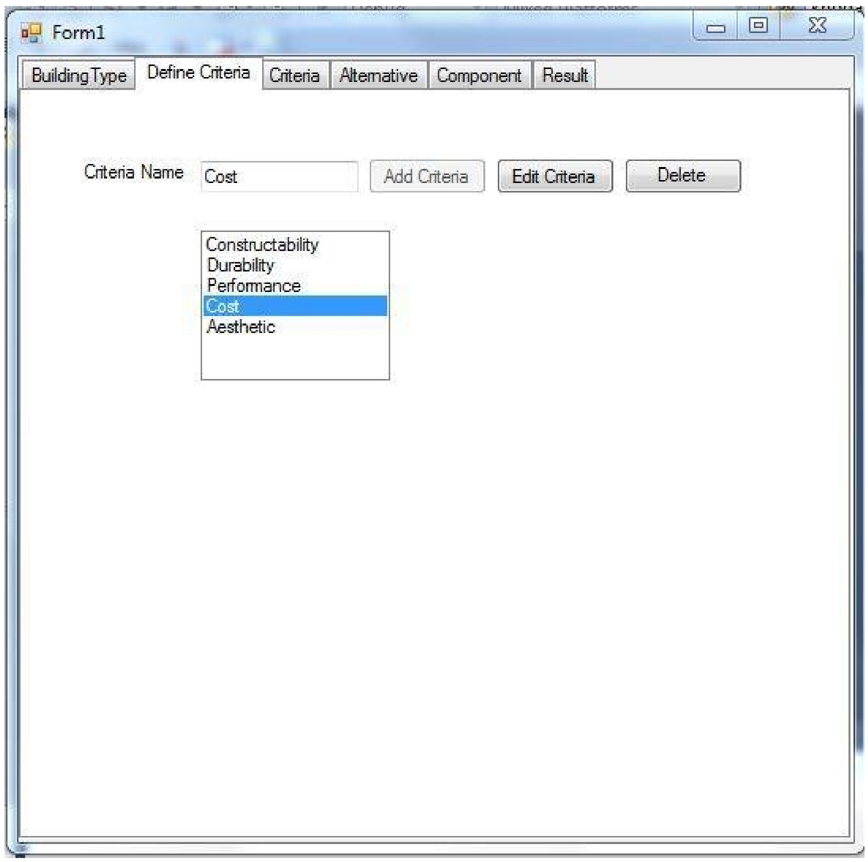


Figure 4-2-Model Interface- Select Criteria

Aside from the building type, selected criteria and their relative weight are the main reason that a single solution cannot answer the selection of an alternative for a building. Therefore, criteria considered for each building type play an important role in the last results of value engineering.

The entered building type and criteria will be added to the model database and it can be proposed and used next time the model is running.

3. In the third step the weight of the **criteria** should be defined. The criteria's weight is defined based on users' preferences. As it has been described in the literatures, AHP technique is applied in two steps. First the criteria are evaluated against each other to find their relative weight, and then the alternatives are assessed against each criterion in order to generate the score of each alternative.

   Pairwise comparison is performed for assessment of the criteria being considered; this can be a time consuming process in the application of the AHP; as users are required to answer each comparison twice in order to check the consistency of the answers provided.

   The thesis proposes a model to ease the process of pairwise comparison for evaluating criteria to find their relative weight and automate the process of comparing alternatives with respect to defined criteria in order to find the relative score of them and consequently provide a report for the VE team.

   In the *criteria* tab of the model interface, the user is asked to compare and evaluate the criteria. If the cursor moves toward (+) it would get an integer range from 1 to 9 and if it moves towards (-) it would get the fraction in the range of 1/9 to 1.See Figure 4-3.

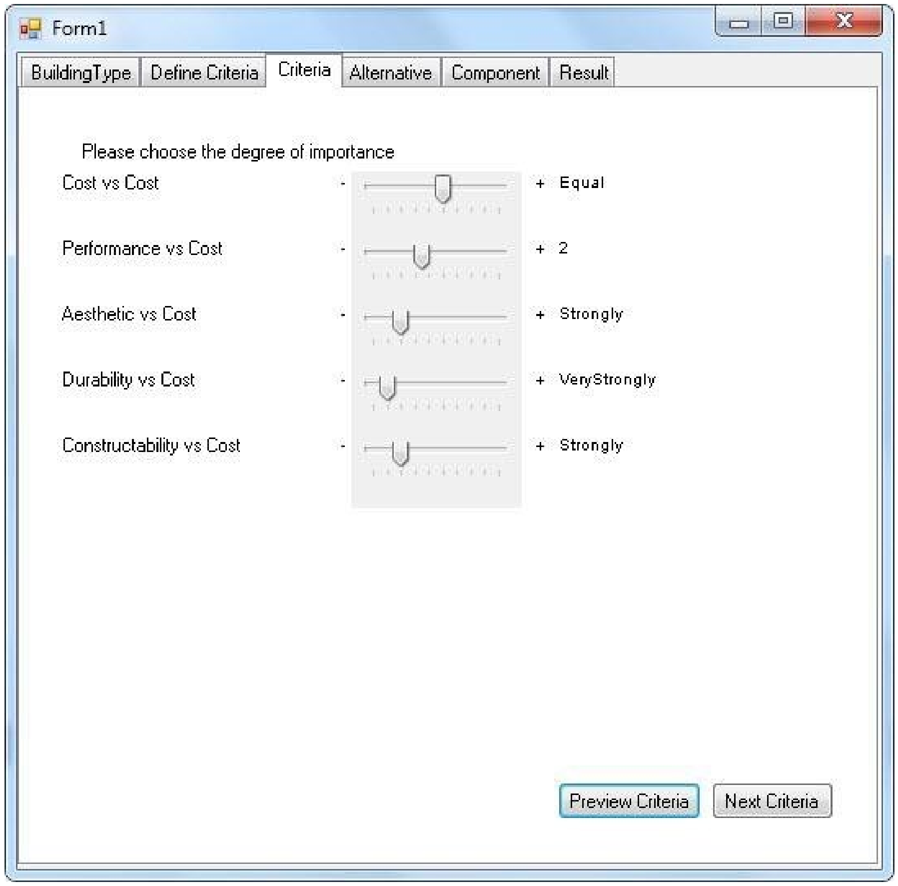


Figure 4-3-Model Interface-Criteria Pairwise Comparison

4. In this step the user is asked to import the considered cost data to the model along with each alternative's BIM output. RSMeans has been chosen as the cost data for this model. Items have been categorized based on Uniformat divisions in RSMeans. Alternatives' BIM models generate the schedule of the components and quantity takeoff of the alternatives. Components in the BIM output have also been classified based on Uniformat division so it can be matched with its corresponding cost in the computational platform.

The user can import as many report (BIM output of the alternatives) as generated in the speculation phase if the value engineering study. Figure 4-4 show the interface designed for user.

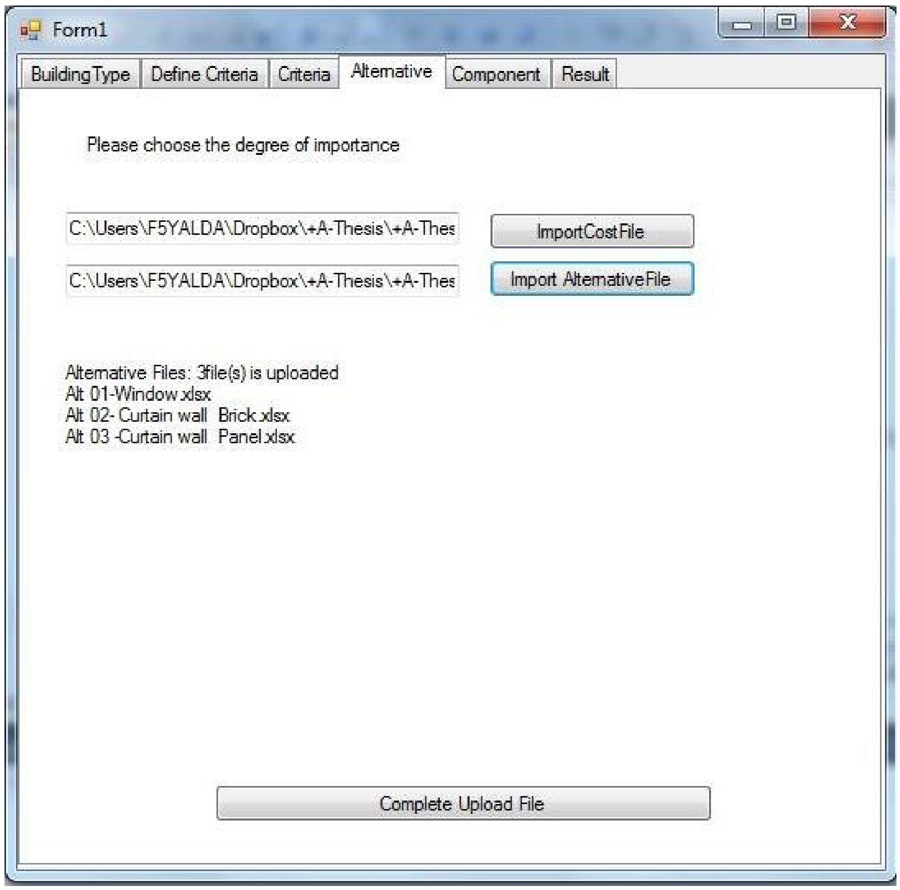


Figure 4-4-Model Interface-Upload Cost Data and Alternatives Quantity Takeoff

5. The model shows every component listed in the Revit model and asks the user to choose a cluster of the components for which he wants to conduct the value analysis. See Figure 4-5 and 4-6. The components are categorized based on the Uniformat II class in the Revit model so in the Revit output the components can

be either selected based on their classes or any of the components can be evaluated individually.

Components specifications such as the Type of the component, the Level that component are located in, Count of the components; Assembly code and Assembly description are included in the BIM output and can be revised by the user. Any other specifications can be embedded in the model as the user preference.

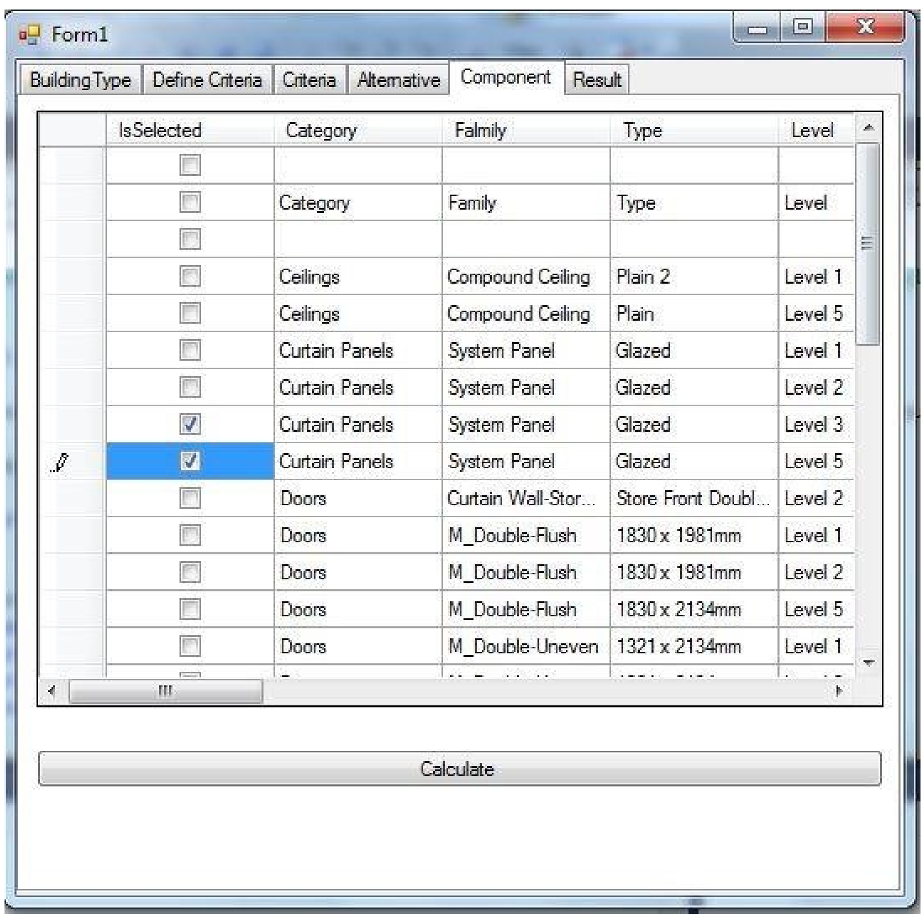


Figure 4-5-Model Interface-Select the Components

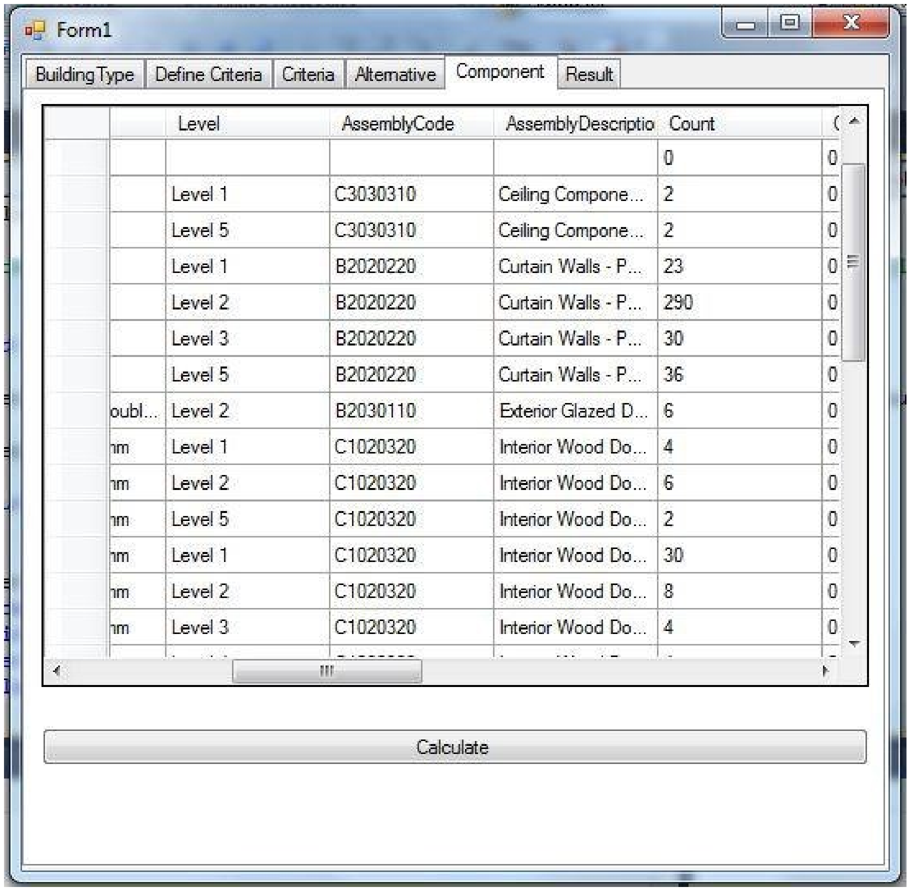


Figure 4-6-Model Interface-Select the Components

6. Alternatives are evaluated automatically in the computational platform. In this process, data pertinent to the project components being evaluated are generated directly from the project BIM model. The components are classified based on Uniformat divisions in the Revit model. The quantity takeoff of the BIM model is linked to a cost data base RsMeans, which has been categorized based on same division as Revit, in the developed model, hence the cost of the alternatives is estimated consequently. Depends on the cost weight, the score of each alternative regarding cost would be determined.

7. The alternatives would be evaluated and compared based on each alternative score, using the AHP technique. The model will rank the alternatives in its output reports. See Figure 4-7.

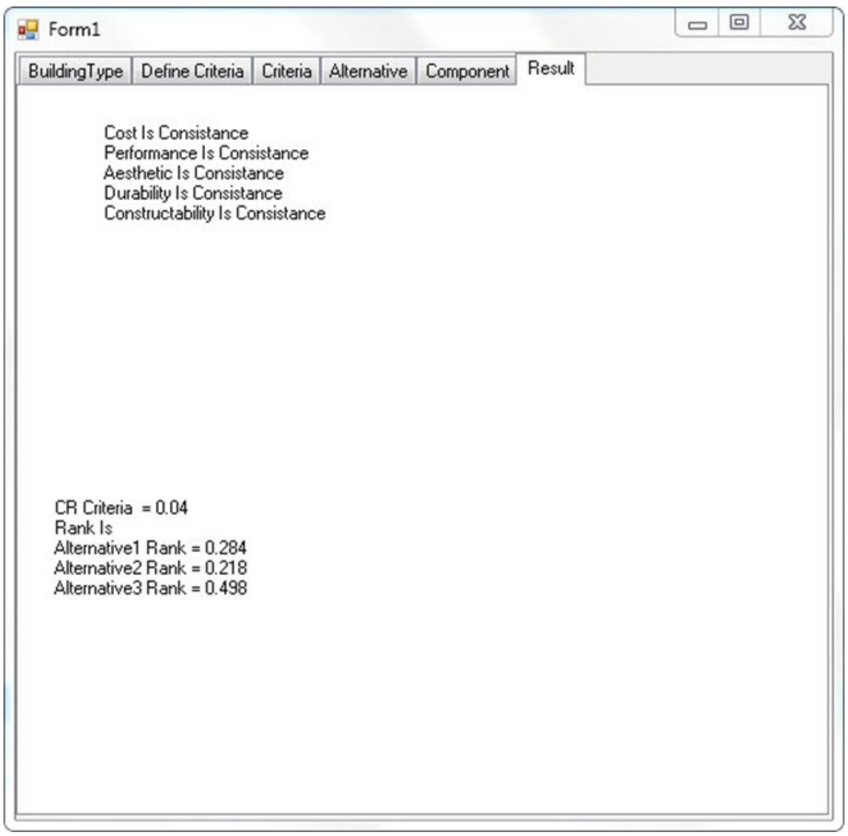


Figure 4-7-Model Interface -Final Result

4.3 Model Evaluation Scheme

This section will explain how the model was implemented in order to convert qualitative assessment of the criteria to a quantitative assessment, normalize data and calculate the entered data in the model using the AHP algorithm and run the evaluation process in order to provide the ranking report. As discussed earlier, the assessment process starts with choosing the building type, its related favorable criteria and evaluates those criteria to find out the relative weight of each criterion. Then the data related to each design alternative will be evaluated in the computing platform of the model automatically. The model will provide a ranking report using AHP rules. Figure 4-8 shows the proposed framework of the model in a high level.

A diagram that shows how processes operate with one another and in what order is a sequence diagram. Figure 4-9 and figure 4-10 shows the model sequence diagram. This diagram is a model of interaction diagram. It depicts the objects and classes involved in the scenario along with the sequence of messages exchanged between the objects which needed to implement the operation of the scenario. Operations and the related codes will be explained briefly in the following pages.

Figure 4-11 shows the steps of implementing the model graphically. Data needed in each process has been shown and the interface design for the user to interact with the model in an easy manner.

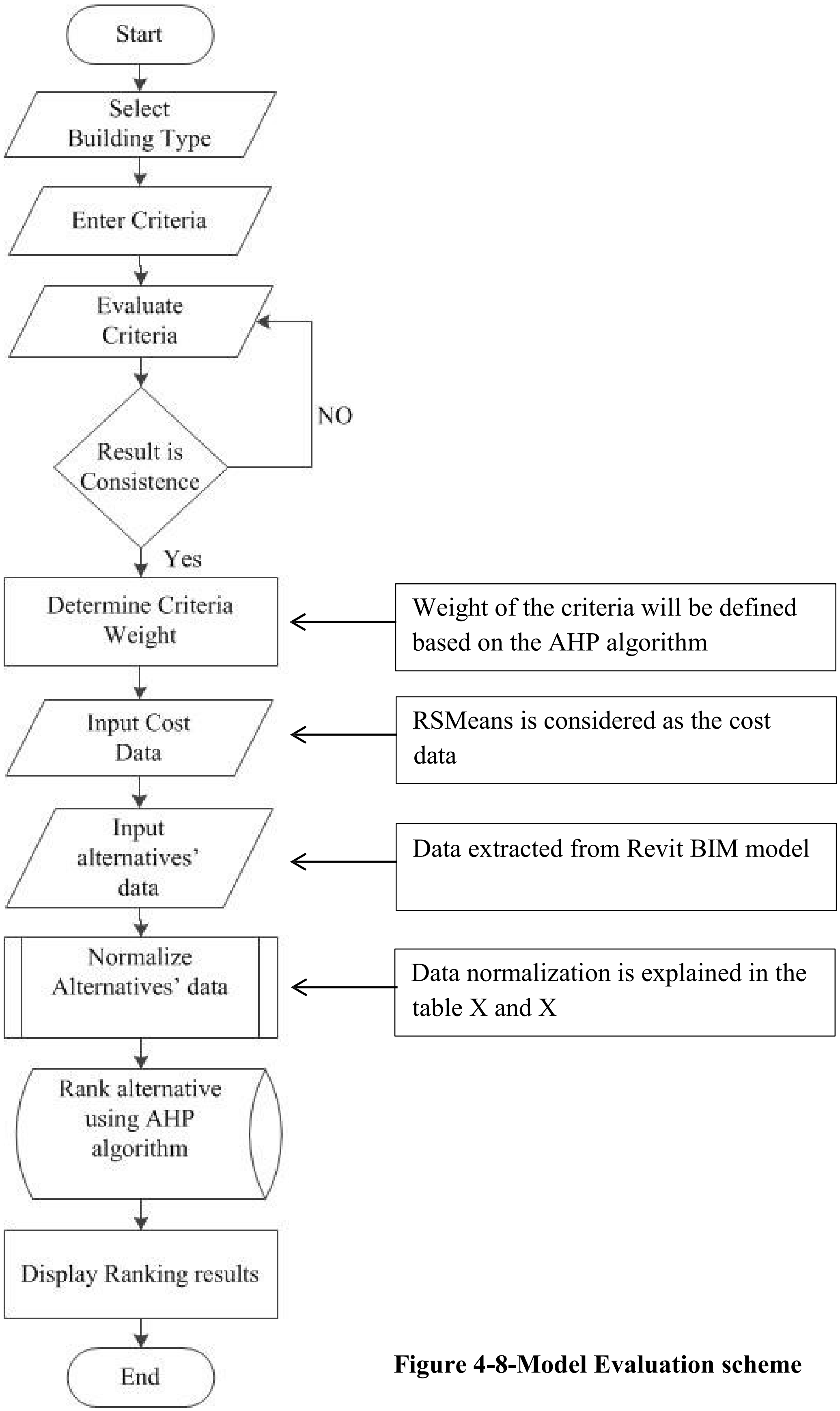


Figure 4-8-Model Evaluation scheme

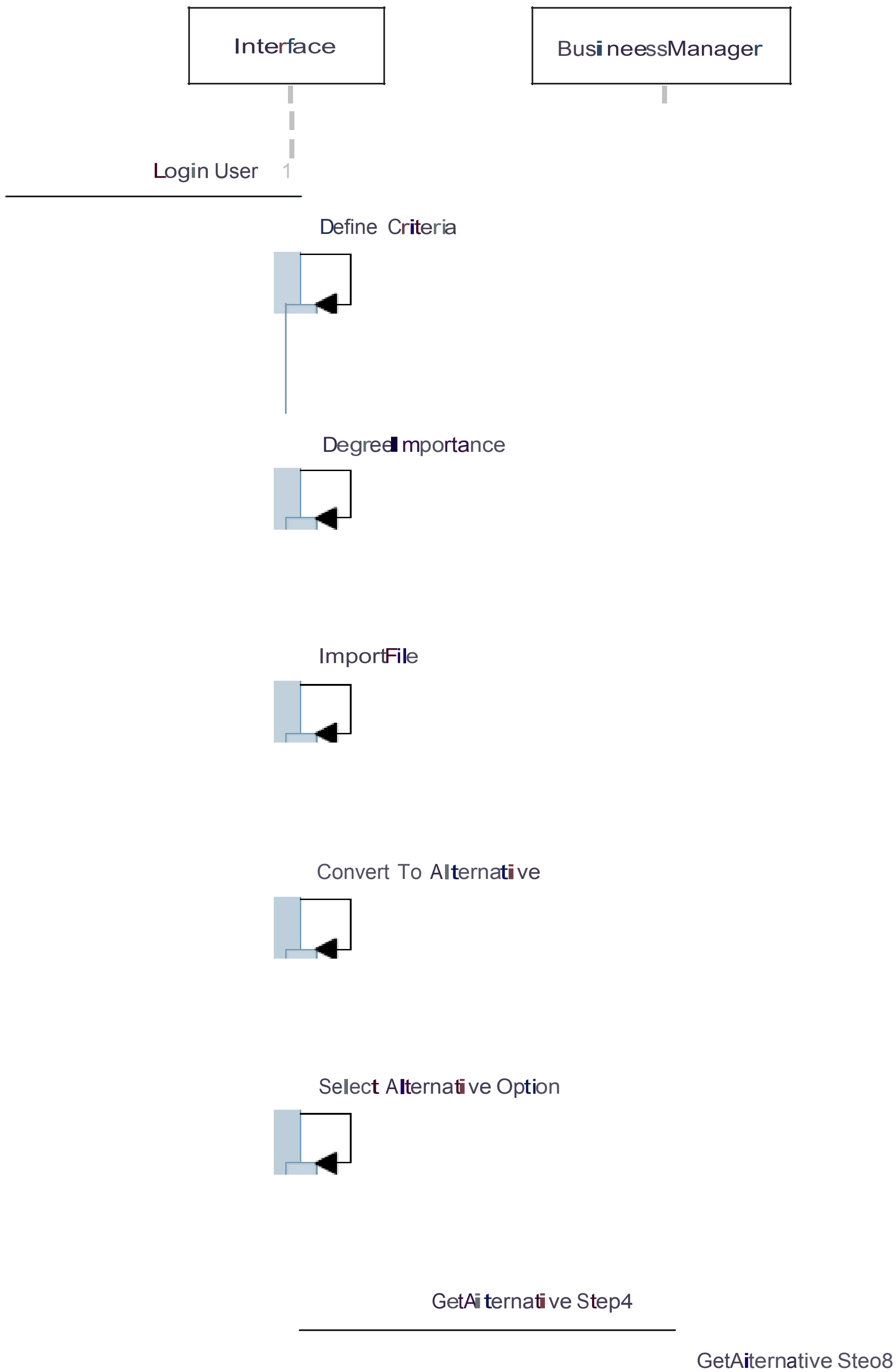


Figure 4-9-Model Sequmce Diagram, Part 1

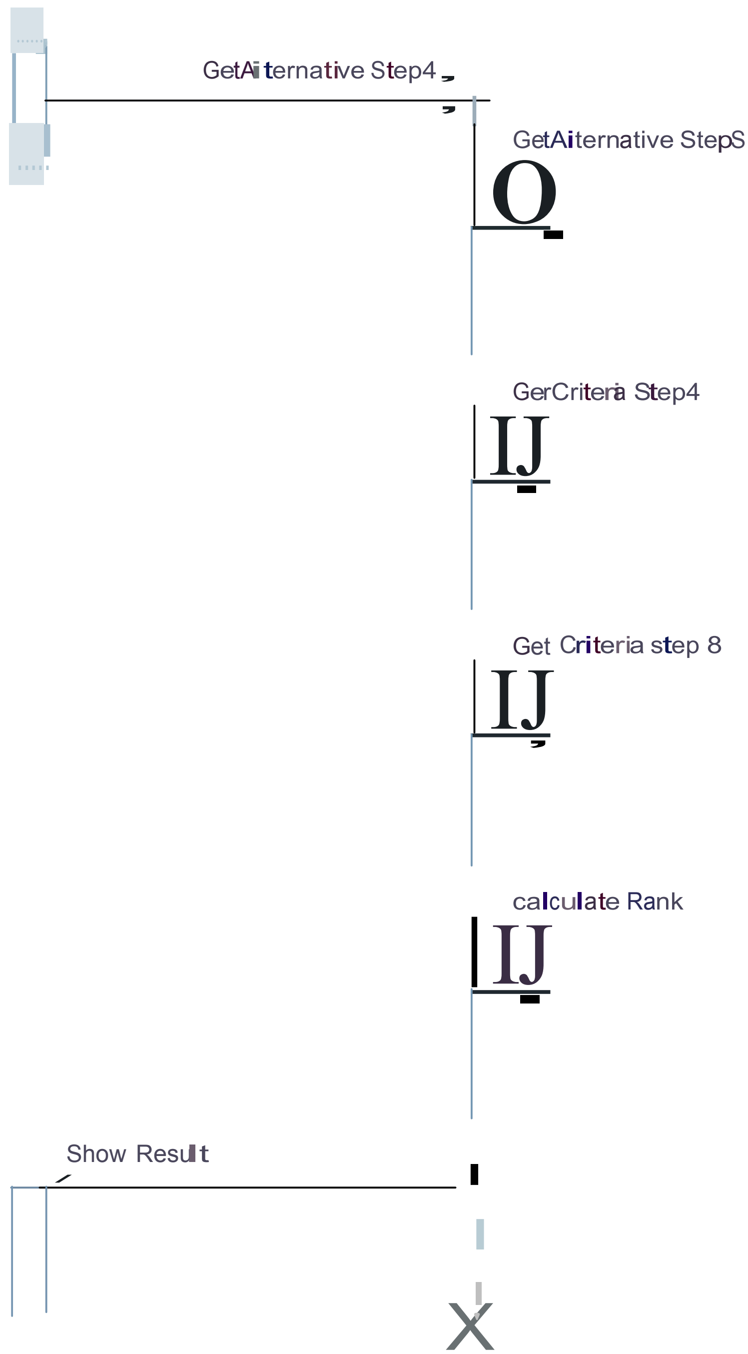


Figure 4-10-Model Sequence Diagram, Part 2

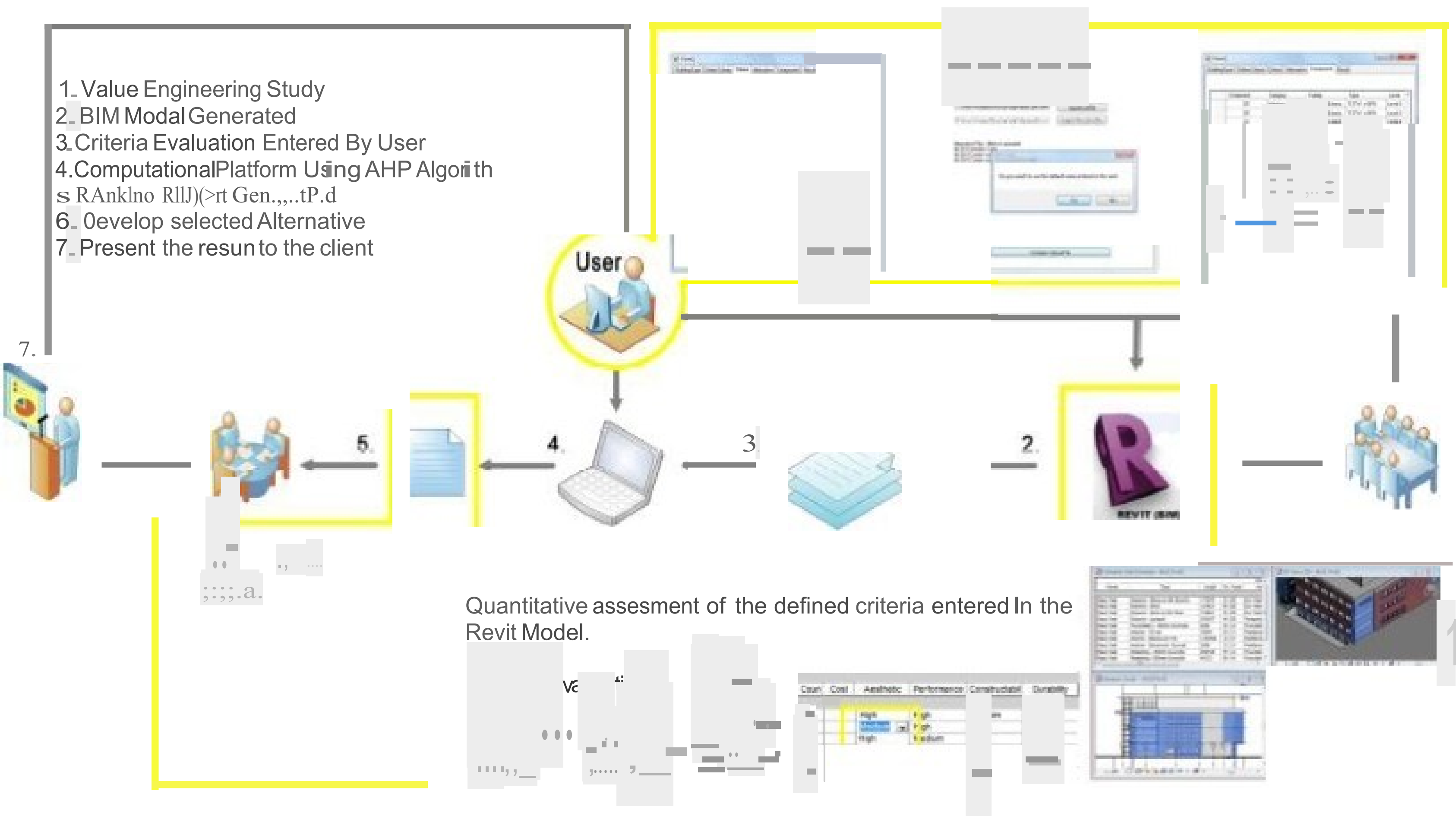


Figure 4-11-l.\i.Iodel Implementation Steps

4.4 Computing Platform Operation

The proposed model uses the AHP algorithm to calculate the input data and generate the ranking report as its output. The application is based on a database system. The database is an organized collection of data. Database management systems (DBMSs) are used in the computational platform to interact with the user, other applications. The database capture, store and analyze data. Well-known DBMSs, SQL is used in the designed model. Data entered by the user, data extracted from the BIM model and the considered cost data for the project are stored in the designed database. Different operations designed for the project are using the database system. Databases are created to operate large quantities of information by inputting, storing, retrieving, and managing that information. Attributes extracted from the BIM model cannot be edited unless it has been changed in the Revit model. Figure 4-12 shows the database developed for the proposed model.

Figure 4-13 shows the class diagram of the model. The class diagram is a static structure diagram that describes the structure of a system by showing the system's classes, their attributes, operations (or methods), and the relationships among objects. Business Manager Class is the main class of the computing model. The attributes of this class are the criteria and the data extracted from the Revit model along with the cost data. Input data will be organized in a matrix. The operation of the business management class is the AHP algorithm. Step 4 and step 8 are the steps designed based on the AHP rules for multiply of different matrix in order to find the criteria weight and the alternatives score. Microsoft Visual Studio 2010, C# related codes can be found in the following pages.

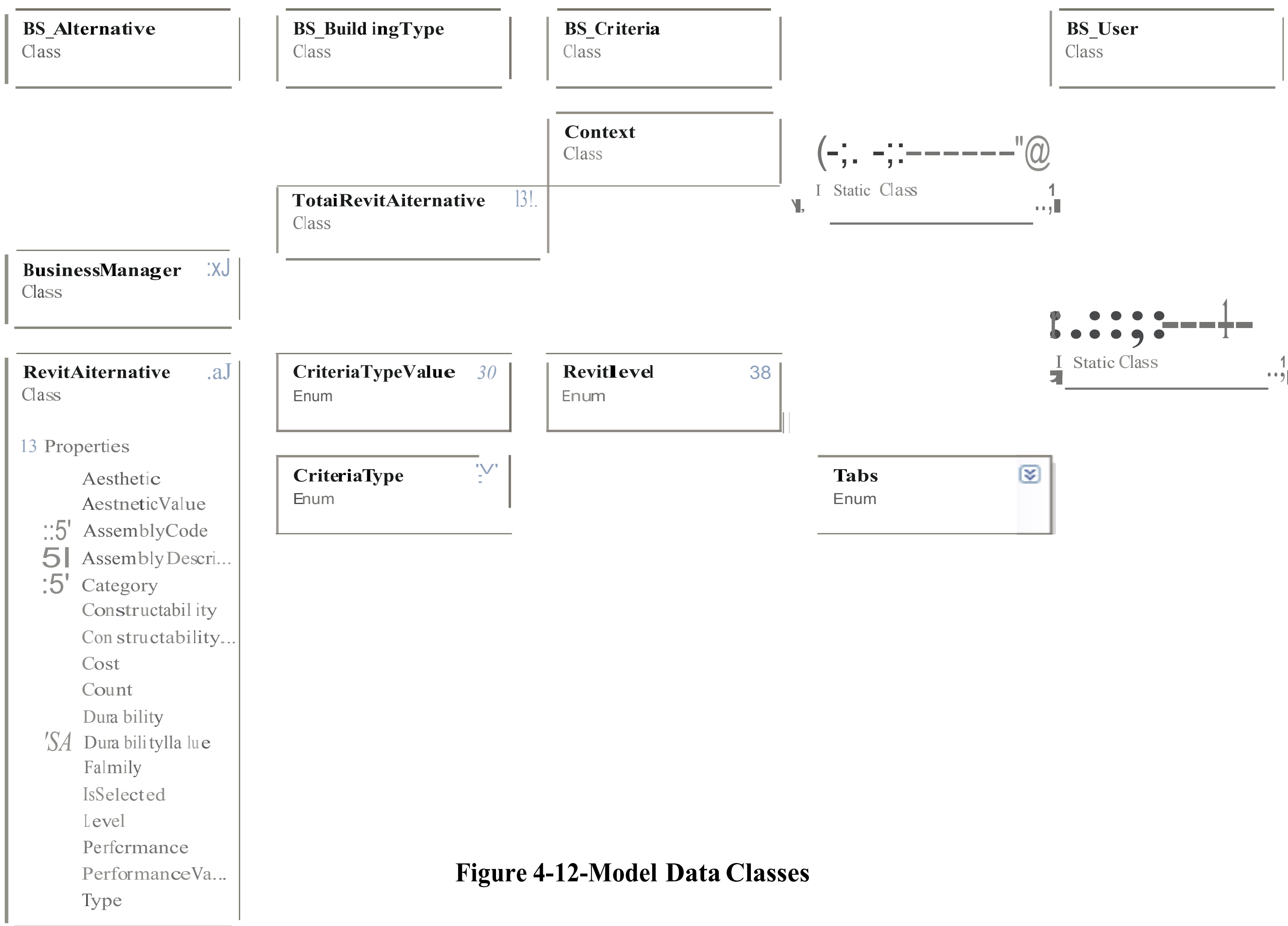


Figure 4-12-Model Data Classes

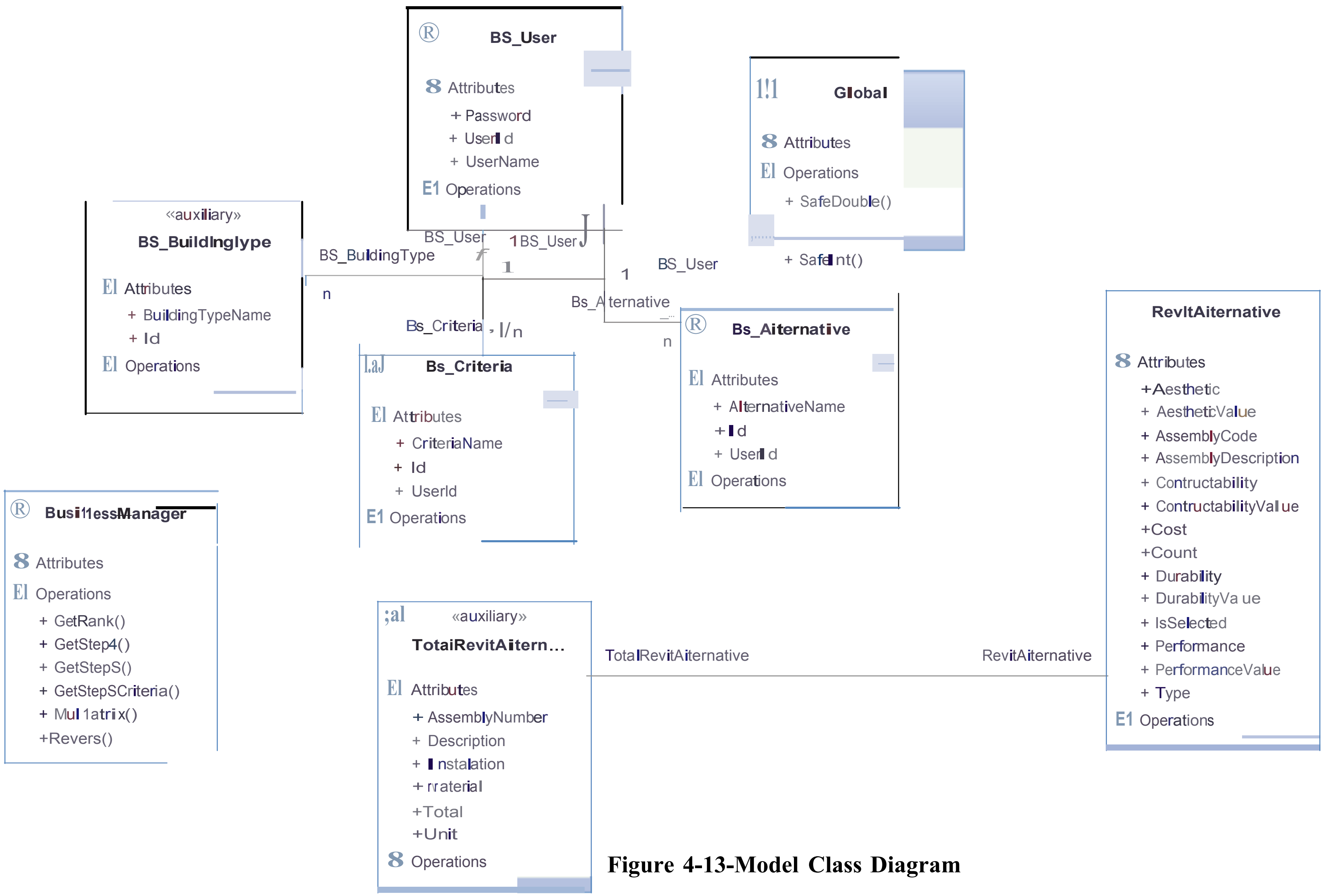


Figure 4-13-Model Class Diagram

```
public static double[,] MulMatrix(double[,] A, double[,] B)
      {

          int N = A.GetLength(0);
          int M = B.GetLength(1);
          double[,] C = new double[N, M];
          for (int i = 0; i < N; i++)
          {
              for (int j = 0; j < M; j++)
              {
                  for (int k = 0; k < A.GetLength(1); k++)
                  {
                      C[i, j] = Math.Round(  C[i, j] +A[i, k] * B[k, j] , 3);
                  }
              }
          }
          return C;
      }

      public static double[,] GetStep4(double[, ,] AlternativeValue)
      {
          int n = AlternativeValue.GetLength(1);
          double[] sum = new double[AlternativeValue.GetLength(0)];
          double[,] result = new double[AlternativeValue.GetLength(0), AlternativeValue.GetLength(1)];
          for (int i = 0; i < AlternativeValue.GetLength(0); i++)
          {
              for (int j = 0; j < AlternativeValue.GetLength(1); j++)
              {
                  result[i, j] = 1;
                  for (int k = 0; k < AlternativeValue.GetLength(2); k++)
                  {
                      result[i, j] = Math.Round( result[i, j]* AlternativeValue[i, j, k],4);
                  }

                  result[i, j] =Math.Round(  Math.Pow(result[i, j], (1.0/n)),4);
                  sum[i] +=Math.Round( result[i, j],4);

              }

          }

          for (int i = 0; i < AlternativeValue.GetLength(0); i++)
          {
              for (int j = 0; j < AlternativeValue.GetLength(1); j++)
              {
                  result[i, j] =Math.Round(  result[i, j] / sum[i] ,4);
              }
          }


          return result;

      }

      public static double[] GetStep8(double[, ,] AlternativeValue, double[,] res4 , ref List<double> landa)
      {
          int N = AlternativeValue.GetLength(1);
          double[] sum = new double[AlternativeValue.GetLength(0)];
          double[,] res = new double[N, 1];
          double[] LandaMax = new double[AlternativeValue.GetLength(0)];
          double[] CR = new double[AlternativeValue.GetLength(0)];
          double[] CI = new double[AlternativeValue.GetLength(0)];
          double[,] tmp = new double[AlternativeValue.GetLength(1), AlternativeValue.GetLength(2)];
          double[,] result = new double[AlternativeValue.GetLength(0), AlternativeValue.GetLength(1)];
          for (int i = 0; i < AlternativeValue.GetLength(0); i++)
          {
              for (int j = 0; j < AlternativeValue.GetLength(1); j++)
              {
                  for (int k = 0; k < AlternativeValue.GetLength(2); k++)
                  {
                      tmp[j, k] = AlternativeValue[i, j, k];
                      res[k, 0] = res4[i, k];
```

Figure 4-14-Sample Code for VS-1

```
public static double GetStep8Criterial(double[,] CriterialValue, double[,] res4, ref List<double> landa)
{
    int N = CriterialValue.GetLength(1);
    double sum = 0;
    double[,] res = new double[N, 1];
    double LandaMax = 0;
    double CR = 0;
    double CI = 0; ;
  //  double[,] tmp = new double[CriterialValue.GetLength(0), CriterialValue.GetLength(1)];
    double[,] result = new double[CriterialValue.GetLength(0), CriterialValue.GetLength(1)];
  int i=0;

        double[,] r = MulMatrix(CriterialValue, BusinessManager.Revers(res4));

        for (int j = 0; j < CriterialValue.GetLength(1); j++)
        {

            result[i, j] = Math.Round(r[j, 0] / res4[i, j], 2); //TODO Division Question of Ranjbaran
            sum += result[i, j];
        }

        LandaMax = Math.Round(sum / N, 2);
        landa.Add(LandaMax);
        CI = Math.Round((LandaMax - N) / (N - 1), 2);
        CR = Math.Round(CI / GetRI(N), 2);


    return CR;

}


public static double GetRI(int N)
{
    Dictionary<int, double> RI = new Dictionary<int,double>();
    RI.Add(1, 0.00);
    RI.Add(2,0.00);
    RI.Add(3,0.58);
    RI.Add(4,0.90);
    RI.Add(5,1.12);
    RI.Add(6,1.24);
    RI.Add(7,1.32);
    RI.Add(8,1.41);
    RI.Add(9,1.45);
    RI.Add(10,1.49);
    RI.Add(11,1.51);
    RI.Add(12,1.48);
    RI.Add(13,1.56);
    RI.Add(14,1.57);
    RI.Add(15,1.59);

    return RI[N];
}

public static double[,] Revers(double[,] CriteriaRes4)
{
    double[,] result = new double[CriteriaRes4.GetLength(1), CriteriaRes4.GetLength(0)];
    for (int i = 0; i < CriteriaRes4.GetLength(0); i++)
    {
        for (int j = 0; j < CriteriaRes4.GetLength(1); j++)
        {
            result[j,i] = CriteriaRes4[i,j];
        }
    }
    return result;
}

public static double[,] GetRank(double[,] alternatuveResult, double[,] CriteriaRes4)
{
```

Figure 4-15-Sample Code for VS-2

Consistency Ratio CR of each matrix is calculated in Step 8. The value of the Random Index RI related to the matrix size is stored in the data base and will be used in the calculation procedure.

Software and systems engineering determine the interaction between a role and a system with a "Use Case". Use Case is the list of steps that define this interaction to achieve the desired goal. The actor can be a human or an external system. Figure 4-16 and 4-17 show the UML use case diagram for the user and system of the designed model.

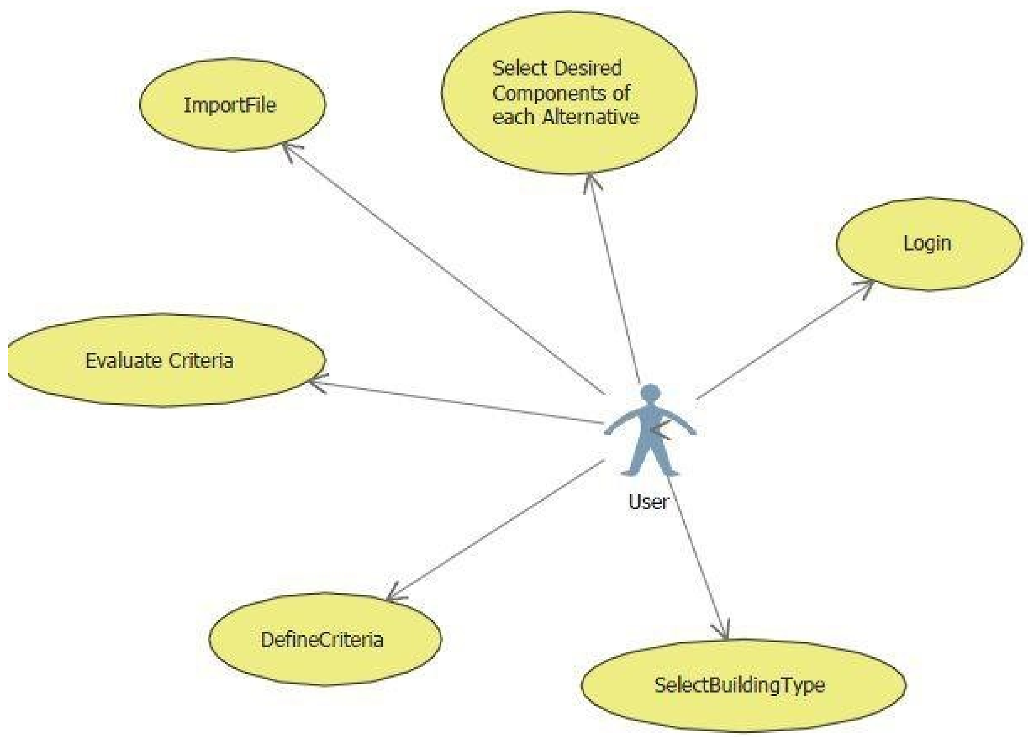


Figure 4-16-Use Case Diagram -User

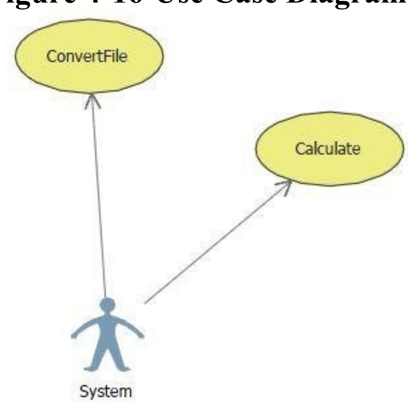


Figure 4-17-Use Case Diagram - System

The prototype model introduced in the methodology has two actors. One is the "User" actor who is the client of the project. It can be the owner or the stakeholder. The user would log in to the model, select the building type, define the criteria, evaluate the selected criteria, import the cost data along with the data extracted from the BIM model and select the components of each alternative. The other actor is the "System" which interacts with the model. It converts the entered data to the matrix and the run the calculation steps of the AHP algorithm.

As mentioned earlier the evaluation of the alternatives versus other criteria is a qualitative assessment. To asses selected components of the alternatives against criteria, the qualitative assessment should be converted to the quantitative assessment. For every component versus the criteria, there is a choice of three values; Low, Medium and High. The intensity scale of importance in AHP technique as Saaty has defined has been broken down into a scale of 1-9, the highest ratio corresponds to 9 and equal importance corresponds to 1. The associated value considered for Low and Medium are 3, 5 respectively and the numerical equivalent of the High is 9. The components are evaluated against desired criteria and the related value is included in the Revit model. These values would be normalized in the calculation process in order to be assessed in the AHP calculation process.

Table 4-1 and -2 are two examples of the data extracted from a Revit model. Unit of each component multiplies by the evaluation value result in the value of that specific component. If more than one component has been selected to be evaluated for the value engineering, the same process will happen to them and the value items are added to the final result. For instance, in the table X, curtain wall has been selected for the value analysis. L_2 is the SF. Amount of the curtain wall. It has a medium performance so its relative value will be ��$_1$ $\times 5$. Later these values are normalized by diving them to the highest value possible for those components. For example regarding performance of the curtain wall and the brick wall: $\frac{L_1 \times 9 + L_2 \times 5}{L_1 \times 9 + L_2 \times 9}$ is the amount entered as the element in the related matrix for the AHP calculation. Same procedure will happen for the evaluation of components against the criteria which have a qualitative inherent.

Table 4-1- Data Extracted from Revit sample

Cost data will be found in RsMeans cost data. Components will match to their correspond cost data in the designed platform

	Type	Length	Assembly Code	Cost	Aesthetic	Performance	Constructability	Durability
	Exterior - Block on Mtl. Stud Ex		B20101443500		High	High	High	High
	Exterior - Brick	L1	B20101305100	L1* Cost/Sf = $ X1	High	High	Medium	High
	Exterior - parapet		B20101531050		Meium	High	Medium	Medium
	Foundation - 300mm Concrete		A1010220		NA	High	High	High
	Interior - Blockwork 100		C10101201600		High	Low	High	Medium
	Interior - Blockwork- Drywall		C10101265800		High	Low	High	Medium
	Interior- 50 mm		C10101265800		High	Low	High	Low
	Retaining - 300mm Concrete		A1010210		NA	High	High	High
	Retaining - 600mm Concrete		A1010210		NA	High	High	High
	Curtain Wall	L2	B20202202000	L2* Cost/Sf = $ X2	High	Medium	Low	Medium
Row 1					=(L1*9)+(L2*9)	=(L1*9)+(L2*5)	=(L1*5)+(L2*3)	=(L1*9)+(L2*5)
Row 2					=(L1*9)+(L2*9)	=(L1*9)+(L2*9)	=(L1*9)+(L2*9)	=(L1*9)+(L2*9)
Normalizing Result				X3=X1+X2	=Row1/Row2	=Row1/Row2	=Row1/Row2	=Row1/Row2

Cost items will be identified

Convert qualitative assessment of selected components to quantitative

Table 4-2-Data Extracted from Revit sample

	Type	Length	Assembly Code	Cost	Aesthetic	Performance	Constructability	Durability/Serviceability
	Exterior - Block on Mtl. Stud Ex		B20101443500		High	High	High	High
	Exterior - Brick	L1	B20101305100	L1* Cost/Sf = $ X1	High	High	Medium	High
	Exterior - Brick on Mtl. Stud	L2	B20101251150	L2* Cost/Sf = $ X2	High	High	Medium	High
	Exterior - parapet		B20101531050		Medium	High	Medium	Medium
	Foundation - 300mm Concrete		A1010220		NA	High	High	High
	Interior - 50 mm		C10101265800		High	Low	High	Low
	Interior - Blockwork 100		C10101201600		High	Low	High	Medium
	Interior - Blockwork- Drywall		C10101265800		High	Low	High	Medium
	Retaining - 300mm Concrete		A1010210		NA	High	High	High
	Retaining - 600mm Concrete		A1010210		NA	High	High	High
	Curtain Wall	L3	B20202202000	L3* Cost/Sf = $ X3	High	Medium	Low	Medium
		Count						
	Windows - Steel	C1	B20201045500	C1* Cost/No = $ X4	Low	High	Medium	High
	Windows - Steel	C2	B20201045500	C2* Cost/No = $ X5	Low	High	Medium	High
	Windows - Steel	C3	B20201045500	C3* Cost/No = $ X6	Low	High	Medium	High
Row 1					=(C4*3)+(L1*9)+(L2*9)+(L3*9)	=(C4*9)+(L1*9)+(L2*9)+(L3*5)	=(C4*5)+(L1*5)+(L2*5)+(L3*3)	=(C4*9)+(L1*9)+(L2*9)+(L3*5)
Row 2					=(C4*9)+(L1*9)+(L2*9)+(L3*9)	=(C4*9)+(L1*9)+(L2*9)+(L3*9)	=(C4*9)+(L1*9)+(L2*9)+(L3*9)	=(C4*9)+(L1*9)+(L2*9)+(L3*9)
Normalizing Result				X7=Sum X(1:6)	=Row1/Row2	=Row1/Row2	=Row1/Row2	=Row1/Row2

Cost items will be identified

Convert qualitative assessment of selected components to quantitative

4.5 Summary

A prototype user friendly computational platform has been programmed in support of the describe methodology and in support of value engineering. It integrates through its database projects' BIM models for automated data extraction and to support visualization, RSMeans for cost estimating data and a coded application of the AHP for assisting users in the evaluation and process and then ranking competing alternatives.

The model is flexible; allowing users to specify different evaluation criteria for each group of project components. This feature minimizes data entry and speed up data processing. It helps to ease the cumbersome procedure of multi criteria decision making.

Chapter Five: CASE STUDY

5.1 General

Chapter five presents the application of the developed model in a case example to demonstrate its use and capabilities and to illustrate the features of the developed computational platform. The case study is implemented as per the same process explained in the methodology. The procedure is also summarized in Figure 5-1.

The process starts when the VE team starts collecting data and decides to generate alternatives in support of the project's objectives. This needs collecting data required to generate the BIM and 4D model as it has been discussed extensively in the model implementation chapter. The computational platform programmed in Visual Basic Studio uses Analytic Hierarchy Process AHP to evaluate data while Autodesk Revit 2013 is used to generate alternatives. The 4D model with the cost as the fourth dimension is made in the computational platform.

The case study is about the building envelope and VE team wants to find the best alternative for the building façade trying different architectural design and materials. Any data missing in the process of modeling the building is assumed. The following sections illustrate the implementation of the case study thoroughly.

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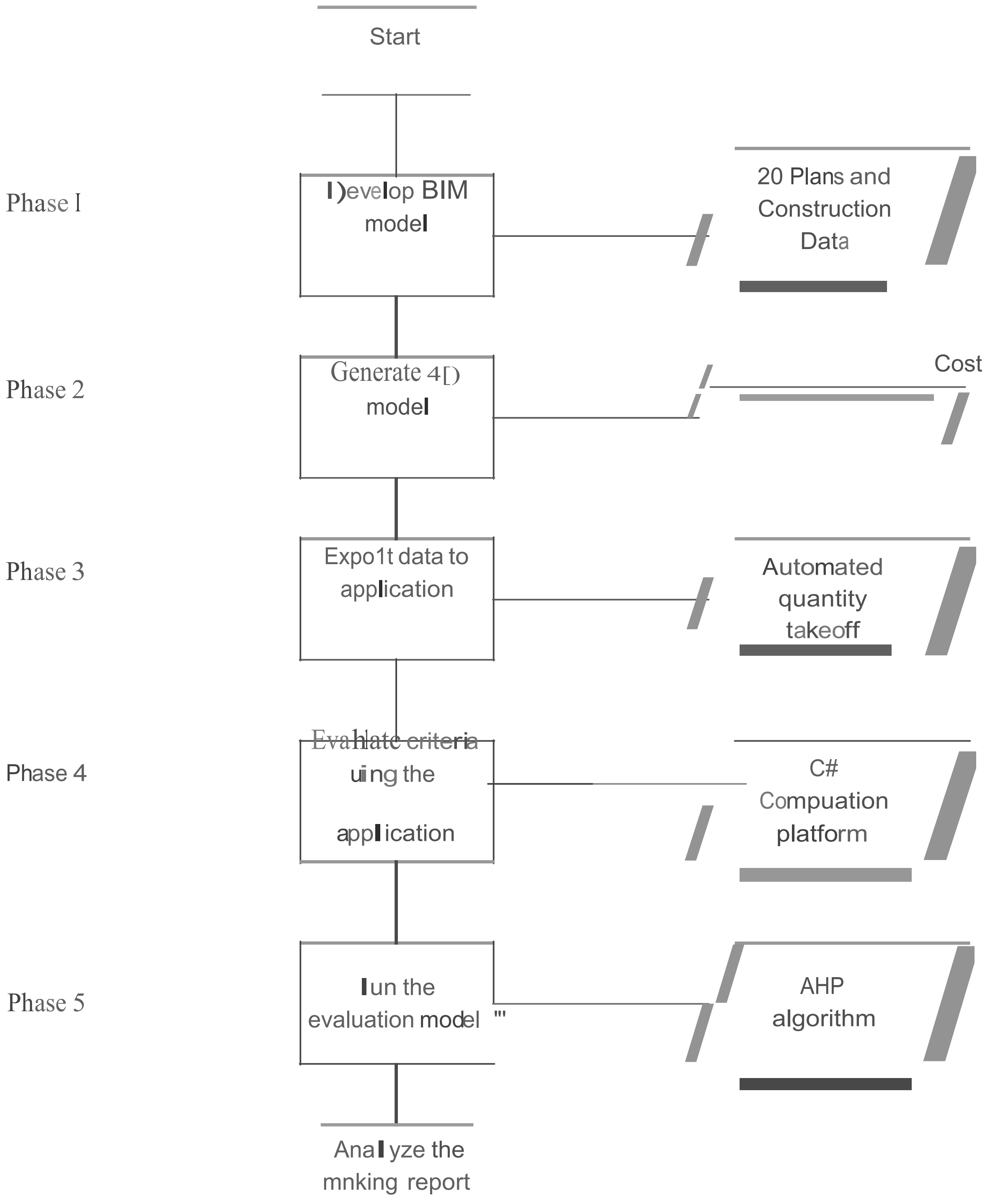

Figure 5-1-Implementation of the Developed :Model in the Case Example

5.2 Project Description

The described model is applied to a case study, as a proof of concept, in order to illustrate its use and efficiency. The case study shows the implementation of the model through the steps described in Figure 5-1.

The considered case study is a four story building located in the Concordia University Campus. See Figure 5-2. The building was constructed during 2010 with the cost of 20 million CAD. It is a laboratory building which is the Center of Structural and Functional Genomics. The building has a basement, ground floor, two typical floors and a mechanical floor. CSFG has four floors – 5,400 sq. meters – dedicated to research facilities. The building is connected to the adjacent Richard J. Renaud Science Complex (SP) through passageways on the second and third floors, as well as a tunnel on the basement level. A tunnel also links CSFG with the Communication Studies/Journalism (CJ) building.

Figure 5-2- Building Location

Figure 5-3 and 5-4 are the current building picture.

Figure 5-3- Project Real Photo

Figure 5-4-Project Real Photo

5.3 Criteria Determination and Evaluation

The model implementation starts when the clients desired criteria is defined and the value engineering team generates a number of alternatives based on them and wants to select the optimum or near optimum alternative which would satisfy the owner's requirements and project conditions. Criteria are evaluated against each other to find the relative weight of each criterion as it explained in chapters three and four.

The building is under the *Educational* building type. A numbers of criteria are proposed for that category in the model. The owner can add, edit or remove proposed criteria. The client's final selected criteria for the case study are; *Cost, Aesthetic, Performance, Durability (Serviceability) and Constructability*. See Figure 5-5.

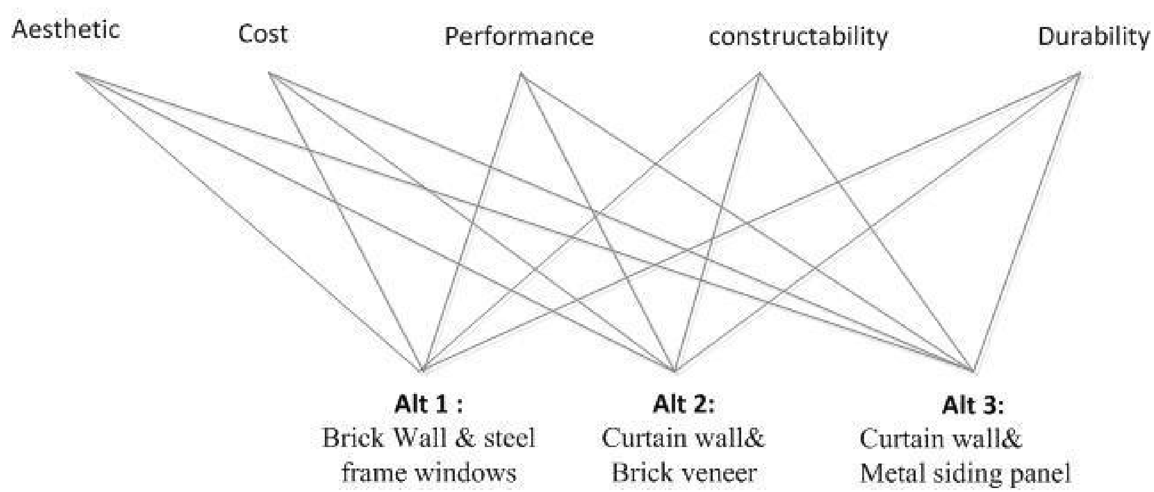

Figure 5-5- AHP Hierarchical Structure

Although the lifecycle cost has not been taken directly into consideration in the evaluation process, it is, however, represented implicitly in the criterion of durability and performance.

The decision maker responds to the pairwise comparison evaluation included in the model in order to establish the weight of the selection criteria. Table 5-1 shows the degree of importance of the criteria elements, entered by the user. The Consistency Ration (CR) of the criteria Matrix, which is calculated by the automated computing platform, is 0.0226 which is quite acceptable (being less than 0.10). Using AHP technique relative weights of the criteria was calculated. See Table 5-2.

Table 5-1-Criteria Pairwise Comparison

	Cost	Constructability	Performance	Aesthetic	Durability
Cost	1	2	3	8	5.000
Constructability	0.500	1	0.500	7	5.000
Performance	0.333	2	1	5	3.000
Aesthetic	0.125	0.143	0.200	1	0.500
Aesthetic	0.200	0.200	0.333	2	1

Table 5-2- Alternative Ranking

Criteria	Weight
Cost	0.435
Constructability	0.224
Performance	0.230
Aesthetic	0.041
Durability	0.070

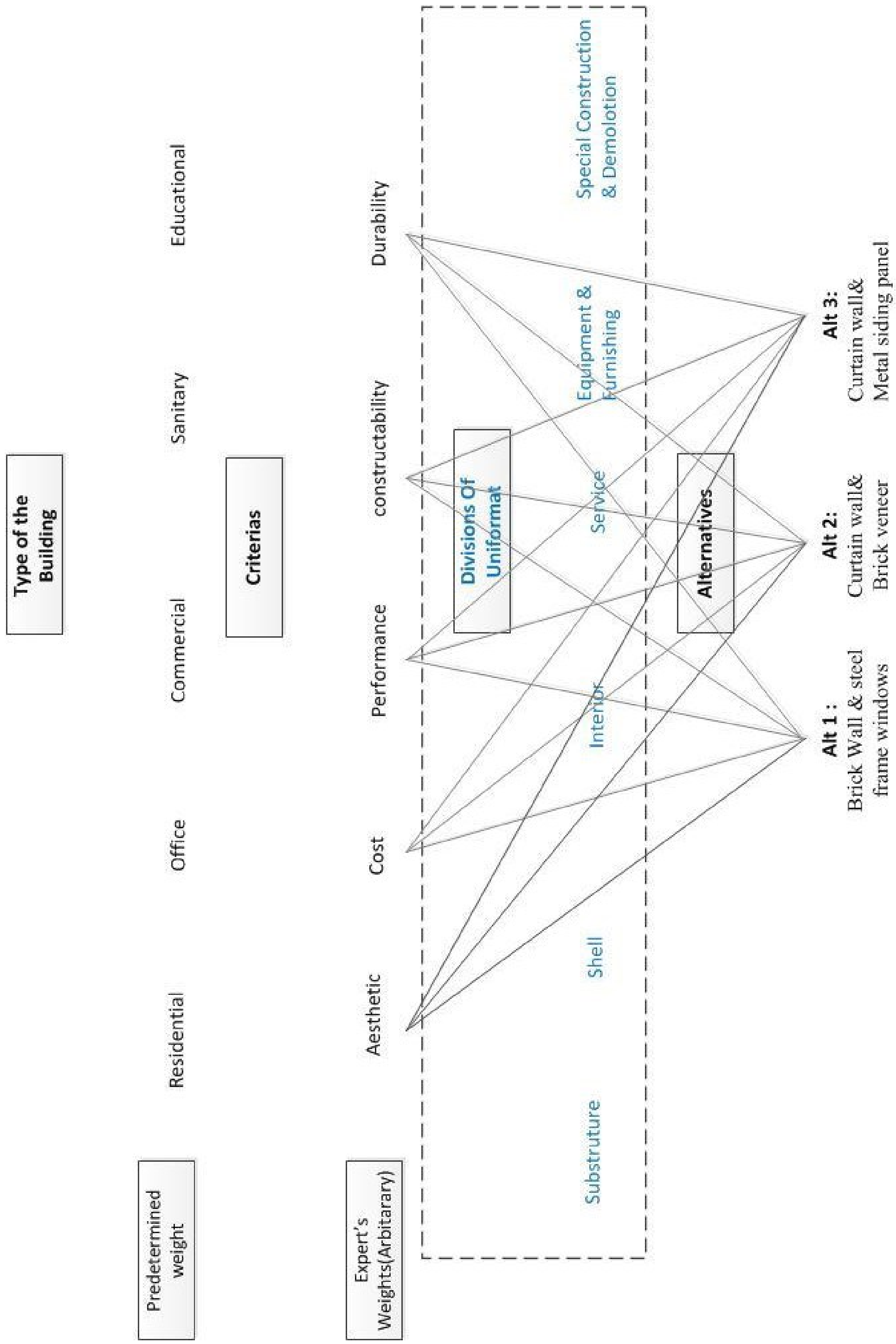

Figure 5-6-AHP Hierarchical Structure

Figure 5-7 graphically shows the AHP diagram of comparing alternatives and criteria and the model classifications.

5.4 Alternatives Generation Using BIM models

All the data needed to construct the BIM model of the alternatives is collected and a BIM model was generated based on the completed 2D plans and other construction data. For every alternative an exclusive BIM model should be made. The value engineering concern is the envelope of the building, so three alternatives for the building's façade with respect to architectural design and materials is considered as below: See Figure 5-8and 5-9.

1- Exterior Brick Wall with single wythe and steel frame windows

2- Curtain wall and Brick veneer single wythe

3- Curtain wall and Metal siding panel

Figure 5-8- Alternative Design of Project Façade

Figure 5-7-Alternative Design of Project Façade

The BIM model is developed based on the completed plans and available construction data such as material, dimensions, specification and so on. All unavailable data needed to generate the BIM model are assumed. Components in the Revit 2013 software are classified based on the Uniformat divisions. Those criteria which are selected based on the client's preferences are added to the BIM model schedule as the project parameters. See figure 5-10.

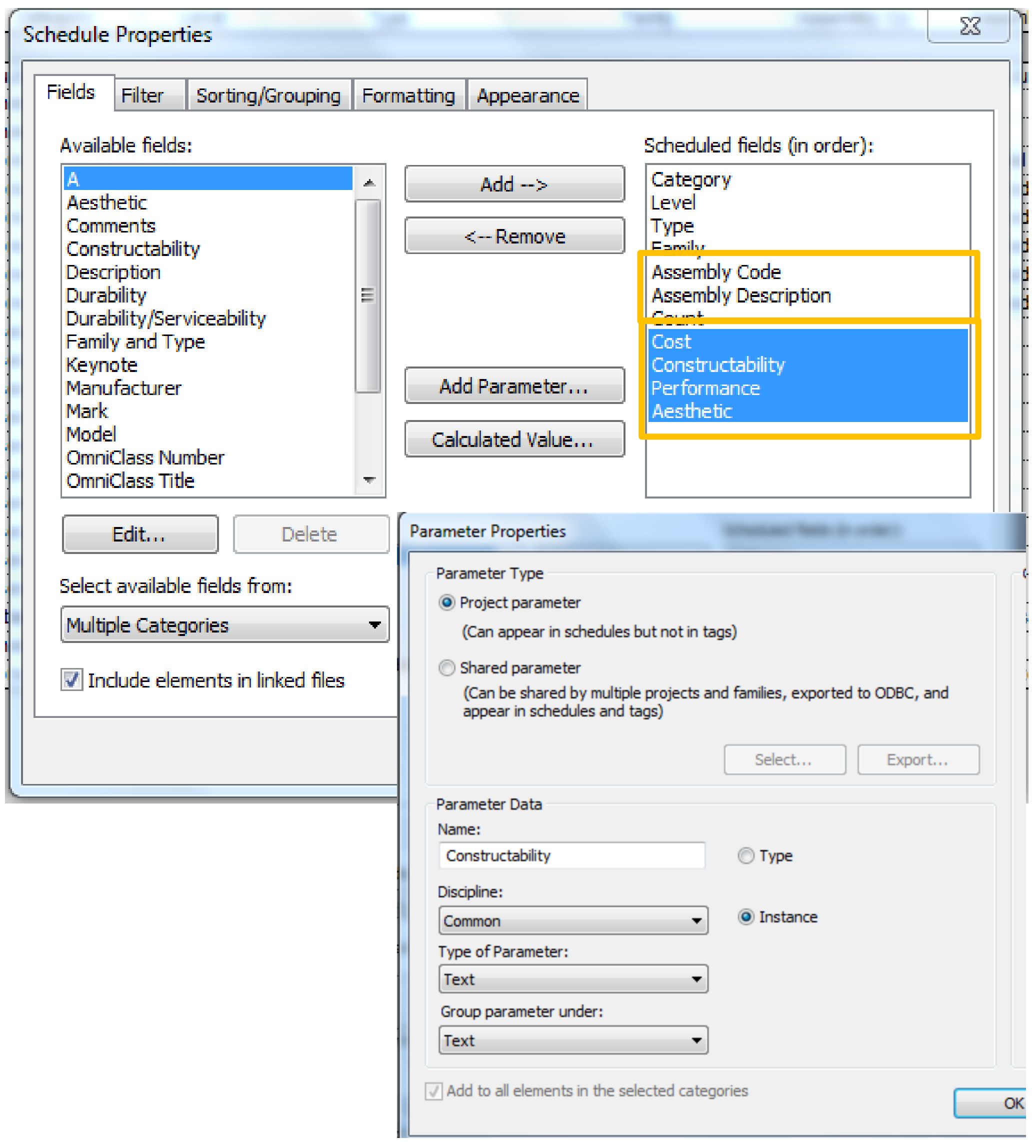

Figure 5-9-Revit Parametric Properties

Since all design components have a parametric relationship with each other, sections, elevations and other details are generated automatically as shown in Figure 5-11.

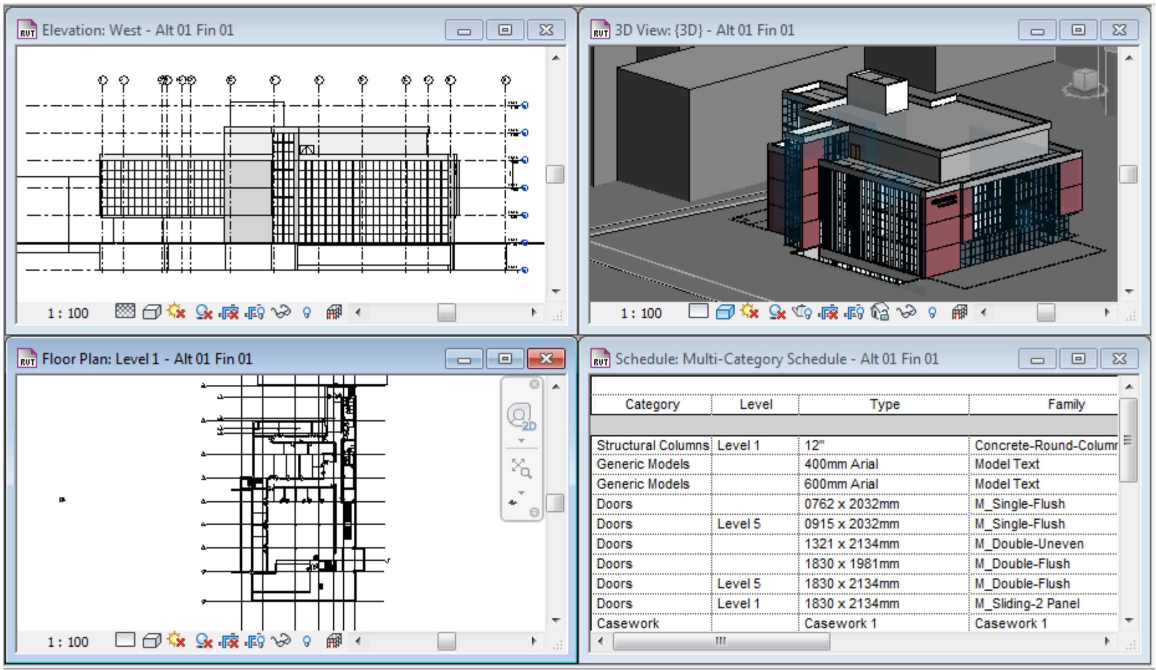

Figure 5-10-Revit Model Views

Using the finished BIM model, schedule of quantities was automatically generated from the BIM model. Figure 5-11 shows a sample snapshot taken from Revit 2013 concerning wall schedule details. Desired criteria have been entered and evaluated within the model. The developer of the 3D model is one of the VE team members (or have full cooperation with them) so the proper value of each component against every criteria is included in the Revit model and in the quantity takeoff output. In order to convert the qualitative assessment of every component versus the criteria, to the quantitative assessment, three choices of Low, Medium and High values is available.

Wall Schedule					
Family	Type	Length	Width	Assembly Code	Assembly Description
Basic Wall	Exterior - Block on Mtl. Stud Ex	173076	220	B2010140	Ext. Wall - CMU
Basic Wall	Exterior - Brick	176379	90	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall	Exterior - parapet	250188	460	B2010200	Parapets
Basic Wall	Foundation - 300mm Concrete	9384	300	A1010220	Foundation Walls - CMU
Basic Wall	Interior - Blockwork 100	1444992	124	C1010120	Partitions - CMU
Basic Wall	Interior - Blockwork- Drywall	3988	124	C1010145	Partitions - Drywall w/ Metal Stud
Basic Wall	Interior- 50 mm	34858	50	C1010145	Partitions - Drywall w/ Metal Stud
Basic Wall	Retaining - 300mm Concrete	302748	350	A1010210	Foundation Walls - CIP
Basic Wall	Retaining - 600mm Concrete	40162	600	A1010210	Foundation Walls - CIP
Curtain Wall	Curtain Wall	371331		B2020200	Curtain Walls

l Schedule					
Assembly Description	Cost	Aesthetic	Performance	Constructabil	Durability
Ext. Wall - CMU		High	High	High	High
Ext. Wall - Brick Veneer w/ Stud		Low	Low	Medium	Low
Parapets		Meium	High	Medium	Medium
Foundation Walls - CMU		NA	High	High	High
Partitions - CMU		High	Low	High	Medium
Partitions - Drywall w/ Metal Stud		High	Low	High	Medium
Partitions - Drywall w/ Metal Stud		High	Low	High	Low
Foundation Walls - CIP		NA	High	High	High
Foundation Walls - CIP		NA	High	High	High
Curtain Walls		High	Medium	Low	Medium

Figure 5-11-Quantity Schedule Of Components

The model then shows every component listed in the Revit model and asks the user to choose a cluster of the components for which he wants to conduct the value analysis. As previously mentioned, the concern of the VE team is the building façade so the components selected for comparison are the *curtain wall, steel frame window* and the *exterior brick wall*. The user is asked to import each alternative's BIM output along with considered cost data to the model. RSMeans have been chosen as the cost data for this model. Items have been categorized based on Uniformat divisions in RSMeans. The components of each of the three alternatives also were organized in the Revit model based on Uniformat divisions so they are matched to their corresponding cost when linked to RsMeans data in the automated model.

5.5 Evaluation of Generated Alternatives

The tedious and time consuming procedure of pairwise comparison on each component of the alternatives against every criterion is eliminated in the developed model. The alternatives are evaluated against the criteria automatically in the computational platform. After selecting the components needed to be evaluated; the model generates a report that ranks each competing alternative for the value engineering team.

To obtain the overall ranking of the alternatives, weights of the criteria in the table 5-2 is multiplied by the alternative scores, acquired from the automated comparison in the model based on AHP algorithm. See Figure 5-13. The generated results are summarized below:

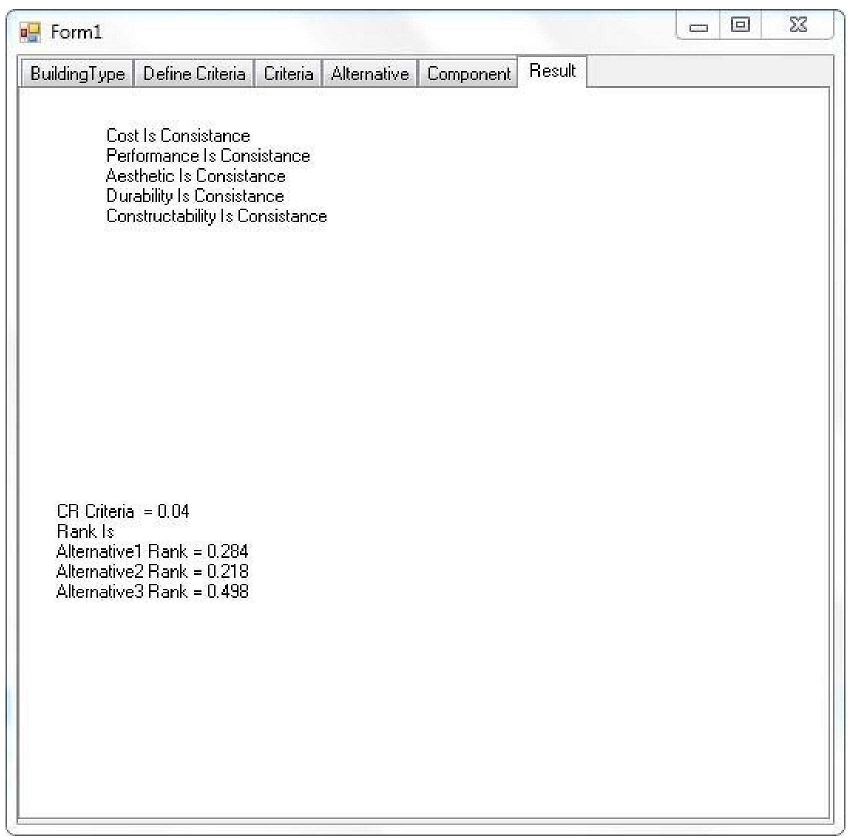

Figure 5-12-Model Interface - Result Tab

Overall rank of alternative 1: 0.3561

Overall rank of alternative 2: 0.3655

Overall rank of alternative 3: 0.2784

The ranking of the first two alternatives are close to each other so the user may choose either one of the two or revisit the criteria and perform sensitivity analysis, if needed.

Chapter six: Summary and concluding remarks

6.1 General

This thesis presents a method to address the challenge faced by professional designers, stakeholders, owners and members of the value engineering teams regarding the selection of the most suitable alternative that suit all the owners' requirement. It proposes an automated integrated computational platform in support of VE analysis. A prototype decision support model is developed to evaluate various alternatives based on the criteria considered for the desired function.

It should be noted that the evaluation process proposed in this research is a Value Analysis rather than Cost Analysis, since it accounts for other critical factors in the evaluation process. In other words, Value Engineering goes beyond cost engineering or cost-benefit analysis. Value engineering can be considered as a paradigm and umbrella that takes into account all aspects needed for evaluation.

This method uses the advanced technology tools used in the construction field like building information model (BIM) and 4D (3D plus cost) models. BIM model was used to provide visualization capabilities for VE team members, owners and designers along with automated data extraction for comparing different alternatives. 4D model was also used to analyze the cost of every alternative and find the relation of the components and cost of the project.

Evaluation of the alternatives with respect to the defined criteria is based on the analytical hierarchy process (AHP). AHP was used to find the relative weight of the criteria considered for the project interactively with user, as well as assessing the alternatives score. Scale of the evaluation are Equal importance=1, Weak importance=3, strong importance=5, Very strong importance=7, Absolute importance=9. AHP will rank the alternative and provide a report as the model output.

The proposed methodology integrates the mentioned decision making techniques almost in real time. It combines BIM and 4D models and uses RSMeans as the cost data reference. Providing value engineering teams with needed information from BIM, the model will ease the process of generating innovative alternatives for the and assist VE teams to make value driven decisions with regard to owner's desired criteria. The developed platform can quantify the subjective assessment of the criteria and automate the evaluation of the alternatives.

Based on the developed model and the proposed implementation method, a C# computer application is programmed in Visual Basic Studio to combine BIM and AHP and automate the evaluation procedure. Furthermore, it will identify which design components resulted in high cost and can track the changes they make on the alternatives' components both visually and numerically. Thus construction stakeholders can use the model to improve the value of their design proposals.

Owners, professional designers and more importantly the members of the value engineering teams can benefit from the developed application to improve the value of the project and reduce the unnecessary cost without impacting the functional requirement of the project. Moreover, the parties involved in the project, designers, owners and stakeholders will have the opportunity to communicate with each other at every stage of the project and will help them to have the same picture of the project and avoid any misunderstandings.

In the final analysis, perhaps value engineering is no more than the formal application of standard problem solving to building design. However, the benefits of applying such an approach (VE) are undeniable; Designers are forced to take a step back and analyse and revise their work before leading to conclusions. The proposed methodology in this thesis provides the opportunity for value consultants to improve the VE job plan with application of the special techniques and the special knowledge in order to the develop value alternatives.

6.2 Research Contributions

Large buildings projects require commitments of considerable large resources and the application of models such as that developed in this research can be of help to professionals in Architecture, Engineering and Construction industry in developing better understanding and appreciation of project scope of work and in reducing unnecessary cost without impacting the required functional requirements of project components being considered.

A prototype decision support model has been developed. It integrates through its database projects' BIM models for automated data extraction and to support visualization, RSMeans for cost estimating data and a coded application of the AHP for assisting users in the evaluation and process and then ranking competing alternatives. The model is flexible; allowing users to specify different evaluation criteria for each group of project components. This feature minimizes data entry and speed up data processing. The model was applied to a case project to demonstrate its use and capabilities.

The presented model contributes to the field of construction management by:

- Providing a tool that supports Value Engineering teams in the evaluation phase of VE job plan and facilitates and supports these teams in the speculation phase.
- Automating the assessment and evaluation procedure of competing alternatives in a timely manner.
- Providing the opportunity for the VE team members to track and analyze the consequences of every single change they make in an alternative and identify the components that have the most impact on cost in near real time.
- Facilitating visualization capabilities that can be of help in emerging a mutual clear picture of the project among the VE team members, owners and designers. Moreover to assist VE team members in the process of generating creative alternatives in the speculation phase of VE Job plan.
- Broadening the use of object oriented models within VE context, well integrate BIM models with 4D presentation to provide a tool for Value Engineering team members to be able to evaluate alternatives automatically.

6.3 Recommendations for Future Researches

Despite the benefits model provide for the VE team members and enhance the speculation phase and evaluation phase of the VE Job plan, future works can be done to improve the implementation of the model and enrich the proposed methodology. Some of the recommendations that can improve the research in general are listed below:

- The model is limited to building projects and cannot be applied in heavy constructions
- The model is applied to a case example to show its benefits, however more case studies can be conducted to better examine the computational model and to find its limitation in different projects
- The cost data considered for the model take the direct cost into account. Moreover life cycle cost is not included in the calculations

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