A COMPUTER SYSTEM FOR MULTI-CRITERIA COMPARATIVE EVALUATION OF BUILDING ENVELOPES

Irena Gololov and Abraham Yezioro

Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology
Technion City, Haifa 32000, Israel
Email: ayez@tx.technion.ac.il

ABSTRACT

A computer system for enabling designers and entrepreneurs a simple, convenient and quick manner to select different building technologies for the building's envelope is presented. The selection is achieved by examining the profitability of each alternative, while presenting its performance ability on the basis of a large number of criteria. This paper looks at the application of multiple criteria decision making (MCDM) techniques in the assessment of environmentally sensitive construction methods. Cost benefit analysis is one of the conventional techniques used widely by public and private sectors in the appraisal of projects by means of a market approach. However, externalities, intangibles and environmental impacts need to be incorporated into the evaluation and a strategy needs to be developed to give these factors proper consideration. Due to the fact those impacts can hardly be assessed in economic terms within a market approach framework, MCDM techniques, like Compromise Programming (CP), are investigated and applied to value these impacts in a non-monetary approach. The system is planned as a comprehensive instrument, able to solve a variety of multi-criteria problems, in different fields, therefore enhancing the efficiency of the designer's decision making process and possibilities.

KEYWORDS

Multi-Criteria Decision Making, Compromise Programming, Building Envelope

INTRODUCTION

Most of daily decisions are based on intuition, common sense, randomness, or all of these combined. However, in many cases, the decisions to be made are so complicated, that decision makers cannot solely rely on intuitive logic [Schmoldt et al, 2000]. Despite intuitive decision making being acceptable in many of the simple matters, complex problems require much more accurate and strict evaluation methods [Youdale, 1983].

Multi Criteria Decision Making (MCDM) in the building sector is used until today, for supporting technical or economical issues, where efficiency is the more important aspect. The selection of methodologies and building technologies based on their initial or life cycle cost is a typical problem that can be solved using Decision Analysis (DA) tools. However, the use of these tools for environmental problems presents a lack of consistency between theory and practice, where subjective values were reduced to economical terms. The building aesthetics or environmental comfort were expressed as a cost/benefit measurement. The main argument against the use of MCDM procedures in the design process was that designers dealing with complex issues related to environmental and social aspects were compelled to ignore all those factors. Hence they were forced to base their decisions on an external common denominator (Kirk, 1988). However, thanks to the developments occurred during past decades in the DA field and the increasing use of computer resources, support methods for the decision making were developed and made more comprehensive. Those methods are used today for a wide range of design problems. Decision makers are expressing a growing interest in these support methods, as well in the requirements for their improvement. Questions like reducing time and funding, direct participation of the decision makers, and providing mechanisms to consider the preferences of those involved in the decision making process are among those asked for the improvement of those methods. A proper answer to those requirements will provide designers a powerful tool to make the decision making process more clear, rational and effective.

The large number of existing building technologies and parameters affecting their operation, presents the designers and entrepreneurs with substantial difficulty as they strive to decide upon the optimal method for erecting a specific construction, under certain conditions. Using the right approach during the decision making process, coupled with computerized support systems, designed to manage and control this process, assist in avoiding severe consequences caused by human errors and lack of systemization characterizing human-beings.

This paper sets forth a special unique approach presenting a decision making process and describes a computerized support system based on this approach. This computerized system will assist the designer in making a decision that will take into account different and complex design factors, the objectives of the project and the preferences of the designers and entrepreneurs.

DECISION MAKING DURING THE COMPARATIVE EVALUATION OF BUILDING TECHNOLOGIES

Selecting the preferred building technology among those available become a critical point during the decision-making process. This selection depends on a large number of criteria and the more design solutions there are, the more complex the solution is. Nevertheless, using the procedure of the MCDM (Multi Criteria Decision Making) enables to easily choose between the solutions demonstrated, in a systematic and detailed manner. MCDM contains a wide variety of mathematical instruments, enabling to compare different alternatives and guiding the decision maker achieve the correct selection.

A computerized support system for comparative evaluation of building technologies for the building's envelope, automates the stages of the MCDM procedure (see Fig. 1). MCDM presents an organized approach for decision making techniques for defining priorities and defines common selection rules [Maguire, et.al, 1994]. In this manner, it assists in advancing decisions made through comprehensive evaluation, according to a specific case. In addition, using the MCDM procedure provides the decision-maker with useful residual-products, such as: controlling the accuracy and correctness of the data required for comparative evaluation, consistent documentation of decisions arrived at, and presenting organized arguments for these decisions.

According to the suggested MCDM procedure, a selection is made from a limited number of predetermined alternatives, meaning, tens or hundreds of alternatives described by their characteristics (criteria). The result of comparative evaluation can be a guiding recommendation for selecting one of the alternatives, or a sub-set that will include the most appropriate alternatives for the solution.

The evaluation and selection process is comprised of the following actions:

1. An input is made of a predetermined set of alternative building technologies (see Table 1), evaluation criteria and criteria measures representing achievements (measured or predicted) of the alternatives in relation to the evaluation criteria into the decision table (see Table 2). The decision table is the main data construction. It represents the collection of criteria method, and therefore, serves as a basis for the different building technologies.

The user defines his attitude to these components. In any case he is not satisfied with the scope of solutions, he may temporarily disqualify different technologies from the list. In such a case, these methods do not participate in the comparative evaluation activity and their data do not impact on the order of recommended methods at the end of the evaluation process. In addition, the user can change the evaluation scales determined for qualitative criteria according to his subjective view.

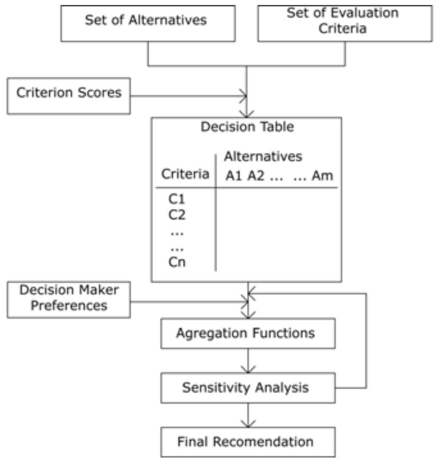

Figure 1 MCDM General Model

2. All criteria have assigned a default weight. However, the user can change it according to his own considerations. A weight describes the importance of the criterion in the user's view and constitutes a scaling factor required in order to link between the value of one criterion and the values of the rest of the criteria. This enables to sum the values and the weights of the criteria into a general index describing the quality of the building technology. Weights define a common "exchange rate" among the criteria. Hence, if the weight of criterion A is twice as big as the weight of criterion B, this means that the decision maker evaluates one point of the grade of A the same as two points as the grade of criterion B and is willing to substitute one with the other.

The user of the system can define the importance of the criterion, starting from its cancellation - value 0 - and up to maximum value - 10.

3. The system calculates the priorities of the building technologies and presents the user with the results of the mathematical analysis.

4. The designer is presented with comparative evaluation results in a manner of recommendation regarding the building technology closest to the ideal one. The designer can compare the position of the method chosen by him with those of the recommended methods and change the different evaluation parameters in order to understand what are the factors affecting the selection.

5. The designer makes a final decision and makes a selection based on all available information, including the results of the comparative evaluation of the computerized system.

Table 1: Building Envelope Technologies

Building Envelope Technology	Description
Nonbearing stacked	Concrete block wall, (5 hole), stucco coating
	Concrete block wall, (4 hole), stucco coating
	Concrete block wall, (4 hole), ceramic tile coating
	Concrete block wall, (4 hole), attached ctone coating
	Concrete block wall, ("Itung"- 25cm), stucco coating
Multicomponent Nonbearing	Concrete block wall, ("Itung"- 20cm), bonded ctone coating
	Concrete ,poured-in-place wall, concrete block added to core, attached stone coating
Double side, Nonbearing stacked	Concrete block wall, (4 hole), concrete block ("Itung"- 7cm) attached to core, stucco coating
	Concrete block wall, (4 hole), concrete block (2 hole) attached to core, stucco coating
	Concrete block wall, (4 hole), face brick coating
Double side, Nonbearing monolithic	Concrete ,poured-in-place wall, stucco coating
Curtain wall - Panel Systems	Composite cast wall panels, stucco coating
	Composite cast wall panels, integrated stone coating
Curtain wall - Grid Systems	Glass panels held in place by aluminum mullions
Second skin façade	Double side Glaz Wall with ventilated air cavity inside

Table 2: Criteria Used in the Computerized Tool

Category		Parameters	Scale Range Measurement
Spatial Characterization	1	Construction intrinsic weight	1-3
	2	Width	mm
Investment Cost	3	Cost of construction	NIS/element
	4	Time of construction	work day
	5	Sensitivity to workmanship	1-5
	6	Difficulty in building construction	1-5
	7	Materials and elements availability	1-3
Long Term Functionality	8	Lifespan	years
	9	Loss of aesthetics	1-4
	10	Cost of lifecycle	NIS/element
	11	Preventive maintenance requirement	1-5
	12	Maintenance requirement	years
	13	Sensitivity to quality of performance	1-4
	14	Difficulty in locating of wear and damages	1-4
	15	Difficulty in performing repairs	1-5
	16	Sensitivity to staining and contamination	1-5
	17	Ability to clean wall surface	1-5
	18	Risk for peeling and cracking	1-4
	19	Risk for visible bent and sensible movement	1-4
	20	Restrictions in accessories mounting	1-4
	21	Sensitivity to humidity	1-5
	22	Sensitivity to daylight and radiation	1-5
	23	Sensitivity to temperature	1-5
	24	Sensitivity to biological influence	1-4
	25	Sensitivity to chemicals	1-5
Weather Penetration	26	Risk for rain penetration into the wall	1-3
	27	Risk for rain penetration through a joints	1-4
	28	Risk for rain penetration through an components	1-3
Indoor Climatic Conditions	29	Energy consumption	Wh/m²/year
	30	Consideration for climate and energy	points
Building Safety Under Extreme Conditions	31	Sensitivity to cracking	1-3
	32	Risk of visible bent and appreciable movement	1-3
Fire Safety	33	Use of flammable materials	1-4
	34	Risk of failure before fire extinguishing	1-3
	35	Probability of formation of a dense smoke	1-4
Acoustic Condition	36	Noise power penetrating from outside	1-3
Environmental Considerations	37	Health damage	1-3
	38	Environmental damage	1-4

THE MATHEMATICAL EVALUATION METHOD

The successful implementation of the evaluation approach on a certain problem depends on the compatibility of the evaluation method used with the data of the evaluated problem. The design process in the building sector provides a large number of situations, in which decision-making, characterized by assessing multi- criteria, is required. The analysis of characteristics and restrictions of the design process in the building sector, presented in this paper, has established that the evaluation technique must satisfy the following conditions:

- Successfully cope with comparative evaluation of different building technologies according to many criteria involved in different areas.
- Refer to quantitative and qualitative criteria.
- To provide the user with the possibility to select a building technology according to one's needs and preferences and to analyze the results in accordance with the amount of risk that one undertakes (for example, through the change of weights).

For comparative evaluation, the system uses the Compromise Programming (CP) Algorithm [Zeleny, 1973]. This method identifies the most approximate solution to the ideal solution based on measuring the distance between the two. CP enables to present the decision maker with a rank of the different building technologies according to their ability to successfully handle the project's set of objectives and limitations.

CP is an accurate evaluation method found most appropriate for performing comparative evaluation of the different building technologies, belongs to the group of interactive methods. Supporting the decision maker is one of the most important aspects among the interactive techniques (Vincke, 1992). The function of the CP technique is not to make the decision for the decision maker, but rather to explain the problem to him: what is permitted, what is the meaning of a certain selection, how the aspect can be improved. This process is supposed to provide the user with additional information (see formula 1).

$$Min \left\{ L_p\left(A_j\right) = \left[\sum_{i=1}^{n} \left(q_i\right) \left[\frac{\left(B_i - F_{ij}\right)}{\left(B_i - W_i\right)} \right]^p \right]^{\frac{1}{p}} \right\} \qquad (1)$$

Where,

Lp - The sum of the distances of the performance abilities of a certain alternative from the ideal performance ability, the decision maker strives to achieve, with regard to each and every criterion.

Aj – Alternative j.

p - A balancing factor $1 \leq p \leq \infty$.

n - The number of criteria.

qi - A weight that constitutes an index for the importance of the ith criterion for the user

$$\sum_{i=1}^{n} q_i = 1$$

Bi - The optimal performance ability that had been achieved by one of the alternatives according to criterion i.

Fij - The performance ability of alternative j according to criteria i.

Wi - The worse performance ability achieved by each of the alternatives according to criterion i.

CP has been chosen as an Aggregation Function for the MCDM procedure due to its simplicity and efficiency. The advantage of this accurate evaluation technique is that it enables synchronic comparison of an unlimited number of criteria, each measured according to different indices. This method requires direct involvement of the decision maker, and hence, he better understands the problem in hand. Moreover, the desires and aspirations of the user change as a result of learning and experience.

The method does not require the decision maker profound knowledge in specific areas of issues related to design and function of building technologies, but usually guides him to a selection with which he feels confident and satisfied. Furthermore, the method does not require the participation of experts in order to formulate complex mathematical models that describe the designers preferences. Hence, saving time and money resources, required for evaluation and selection, increasing the effectiveness of the method in a typical architecture environment.

THE PROPOSED TOOL

For selecting the most appropriate building technology for establishing an external envelope of a certain building, a computerized system has been developed that implements the aforementioned evaluation approach. The computer-aided selection process begins after establishing a set of alternative building envelope technologies, that can be comparatively evaluated (see Fig. 2, sign 1). The minimal number of alternatives required for the activation of the system is two, and the maximum number is not limited. The user can exclude a certain method from the list or to add an unlimited number of building technologies he is acquainted with, if their efficiency is required to be examined for the project. In case of adding additional technologies to the system, the user must input data required by the system, for performing the comparative evaluation. The suggested system performs comprehensive analysis, taking the efficiency of each building technology provided into consideration in financial and qualitative terms (environmental influence, security etc). In most cases, the building technology with the highest weighted efficiency is selected.

When the scope of selected building envelope technologies satisfies the designers requirements, he can view them on the part of the screen that presents a decision table. In this table, he can see the description of the technologies (columns) according to all evaluation criteria (rows) (see Fig. 2, sign 2).

Each of the criteria can be assigned a weight that describes its importance according to the user's view. By assigning a weight 0-10, the user can define the importance of a certain criterion or group of criteria (from cancellation - value 0 and up to maximum importance, value 10) (see Fig. 2, signs A and B).

The user has different evaluation possibilities through assigning a weight to each one of the criteria. The following options also exist:

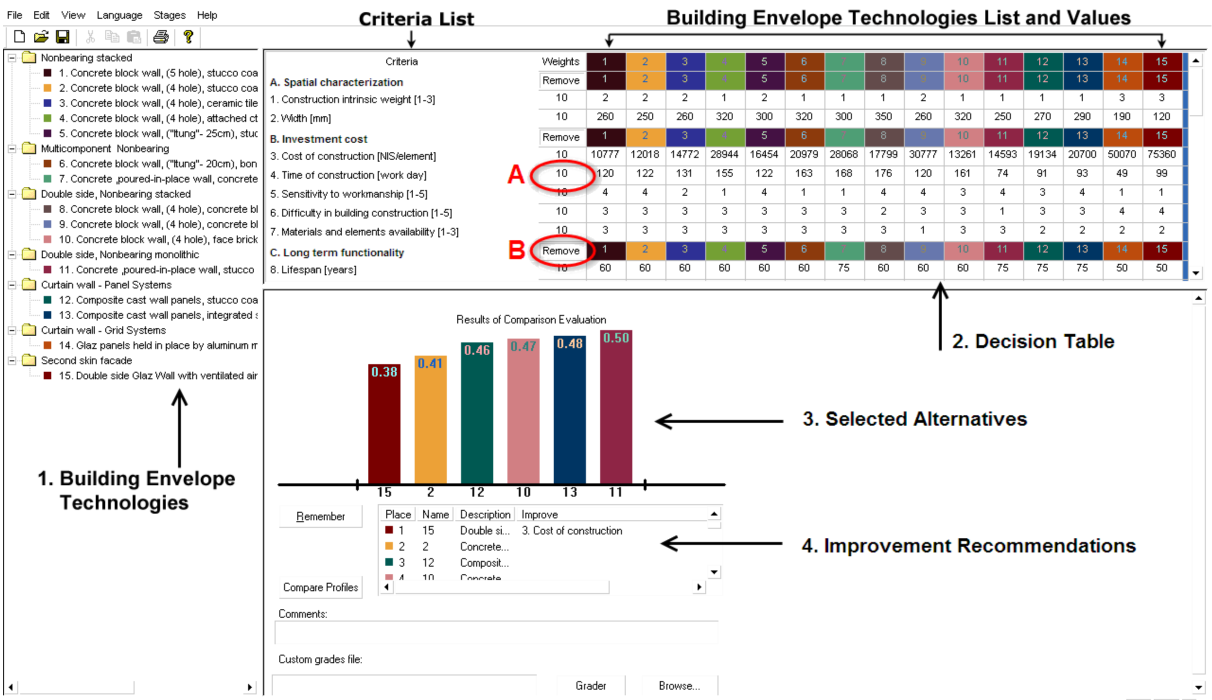

Figure 2 Multi-Criteria Decision Making. Proposed Graphic User Interface

Equal weights **-** According to the default, each one of the criteria is assigned the same weight. Meaning, comparison, according to default, will provide the best technology, according to equal consideration of all criteria.

Different Weights **-**

- Total Selection - The user can perform evaluation according to all criteria, having different weights.
- Partial Selection - The user can perform evaluation only according to criteria he views as important, by disqualifying criteria he views as unimportant.
- Single Selection - The user can perform comparison only according to a single criterion, by disqualifying all the criteria, except one.

The performance ability data of the building envelope technologies in all criteria, are achieved as a result of calculations, simulations and assumptions. The criteria can be divided into two groups: qualitative and quantitative criteria. The quantitative criteria (e.g.: the thickness of the wall, weight, etc) leave no place for doubt - they can easily be measured/calculated. In contrast, the evaluation scale assigned to the qualitative criteria is subjective. If the user's opinion does not accord that of the scale designer - the scale can be modified.

The system's GUI is interactive and enables the user to view the evaluation results, immediately after modifying each of the parameters. After calculating the priorities of the building envelope technologies, the system presents the designer with results of the mathematical analysis through the use of visual presentation means, such as graphs, diagrams, and tables (see Fig. 2, signs 3 and 4, and Figures 3 and 4).

The "Selected Alternatives" area in the screen presents the user with the calculation results of the comparative evaluation in the shape of a bar chart that shows the priorities of the different alternatives for solving the problem. The graph is synchronized with a dynamic ranking table that contains all the methods organized according to their ranking L*p* (for p=2) (see Formula 1 and Fig. 2, signs 3 and 4).

Additionally, a second calculation is performed for finding possible problematic criteria (for p=100). If a method has down-ranked during this calculation (relative to its ranking in the calculation for p=2),this means that this technology has a worse criterion, that stands out, relative to other technologies that previously (using calculation p=2) were ranked under it. In this case, next to the technology's name in the ranking table, appears the name of its worse criterion (see Fig 3, sign A).

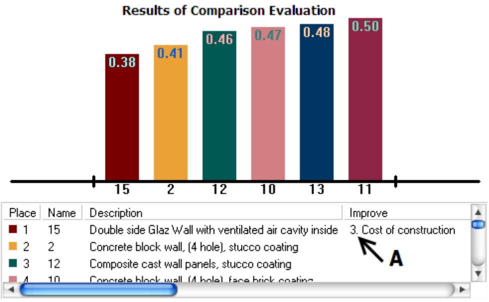

Figure 3 Display of selected alternatives

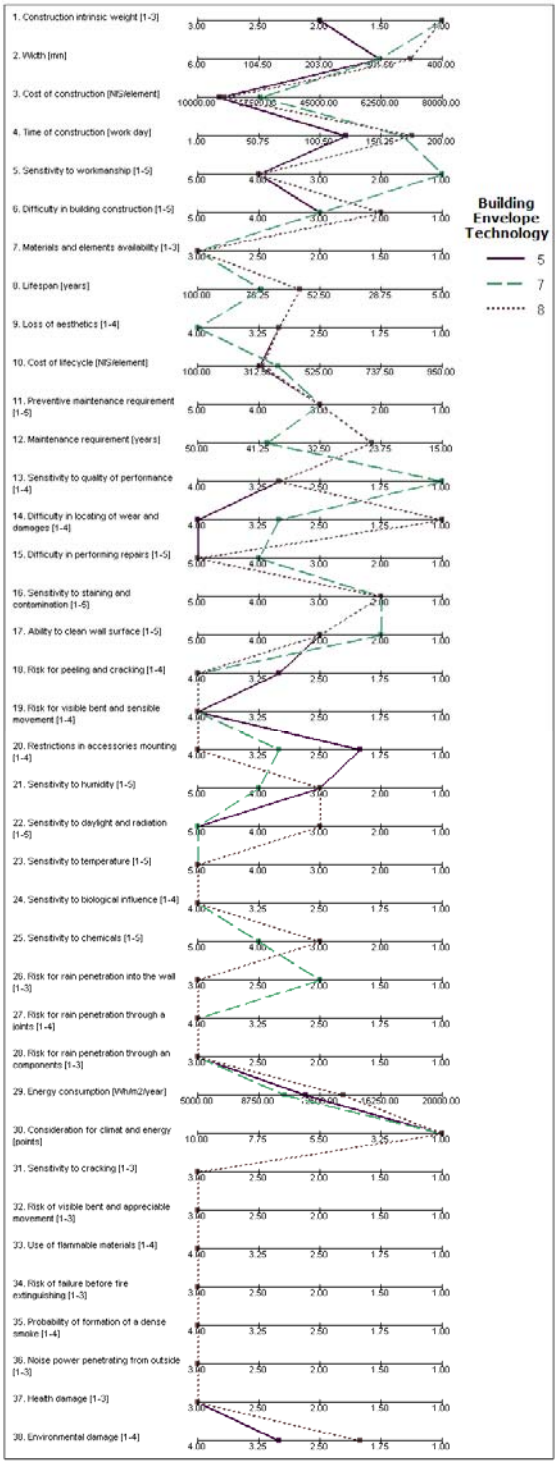

Figure 4 Comparison of Performance Profiles

In the "Comparing Profiles" window (see Fig. 4), appears a graph that compares the best three methods according to the last comparative evaluation performed. The vast majority of characteristics of building technologies require use of evaluation means that will enable simple comparison among the recommended alternatives, and can be understood by the decision maker. This graph enables visual comparison between the functional performances of the building technologies according to the evaluation criteria. Moreover, due to this graph, the user can discover building technologies, with the best or worse performances, according to a certain criterion.

EVALUATIONS USING THE MCDM TOOL

In order to demonstrate the use of the system for comparative evaluation of alternative building methods, the evaluation technique suggested has been applied on 15 building technologies for erecting an external envelope of an office building (see table 1). The technologies are examined according to 38 criteria (see table 2) and afterwards, results of the comparative evaluation are achieved according to changing definitions. Hence, the suggested building technologies and criteria lists can be updated or completed according to local constraints and considerations.

The evaluations performed comprise various situations in order to asses the sensibility and precision of the tool: using only one criterion, using two criteria with different weights and using the whole set of criteria.

1. Evaluation using only one criterion: The criterion aplied was the Cost of Construction included in the Investment Cost group of criteria. We see that the cheapest technology is ranked in the first place, showing a mark of 0.0 conflict, and the more expensive the last (see Figure 5A).

2. Evaluation using two criteria: The criteria used to demonstrate the tool were Cost of Construction and Energy Consumption, included in the Indoor Climatic Conditions group of criteria. Two evaluations were performed: The first, where both criteria had different weights, 10 and 3 respectively, and the second applied the same weight for each criteria, 10 and 10 accordingly (see Figure 5B and 5C). The recommended group of technologies are the same for both cases, but the 2^{nd} and 3^{rd} are changed. The ranking results, though, show that the first case presents less conflict than the second, 0.15 for the selected technology in the first case, and 0.19 for the second, and so on. This can be explained by the more clear influence of one criterion over the other in the first case, so less conflict is expected to occur..

Moreover, a set of evaluations was performed, where the Cost of Construction weight was fixed to 10 and the Energy Consumption changed from 1 to 10. Figure 6 sumarizes the results and changes obtained through the evaluation process. The influence of the weight change is sensed all the way through: from 1 to 3 affects the position of 5 technologies, from 3 to 5 changes 6, from 5 to 8 affects 4, and finally from 8 to 10 affects only 2. Overall 5 building envelope technologies maintained their position.

3. Evaluation using the whole set of criteria: The whole set of 38 criteria was used to demonstrate the tool (see Fig. 3). The ranking values are much higher than in the previous cases, as a result of the mutual influence of the criteria and the presence of more conflicts between them (0.38 for the selected technology).

DISCUSSION AND TOOL ANALYSIS

Comparing the building technologies according to the provided evaluation method suggested by the system, enables arriving at the following conclusions:

A. The system is user friendly - It provides maximum understanding of the relevant problem.

B. The system presents the decision maker a variety of ways for expressing his needs and preferences. The user can:

- Select issues for evaluation by selecting different criteria groups.
- Determine (modify) the values for qualitative evaluation criteria.
- Choose appropriate alternatives for evaluation.
- Prioritize a certain evaluation issue by assigning high weights to chosen criteria.

C. The system is comprehensive enabling to:

- Solve recurring problems under changing conditions.
- Handle quantifiable and non-quantifiable issues altogether.
- The accurate evaluation system for comparative evaluation is not affected from increasing the number of alternatives or evaluation criteria.

D. The system is stable. The sensitivity of the system is adjusted to the conditions of the problem and the nature of its data. The model is not easily influenced from small changes in the problem's data.

E. The system can serve as an educational tool. It immediately presents the decision-maker the impact of his decisions and preferences on the evaluation results. This character enables the user to understand what are the factors that impact the selection of a building technology.

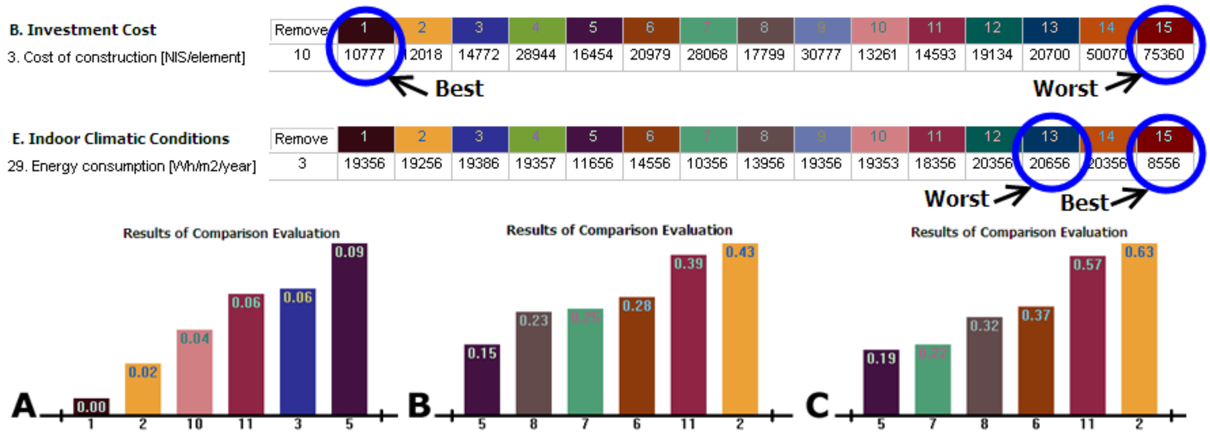

Figure 5 Display of selected alternatives. A. One criterion (Cost of Construction); B: Two criteria, different weight (10-3); C: Two criteria, same weight (10-10) (Cost of Construction and Energy Consumption));

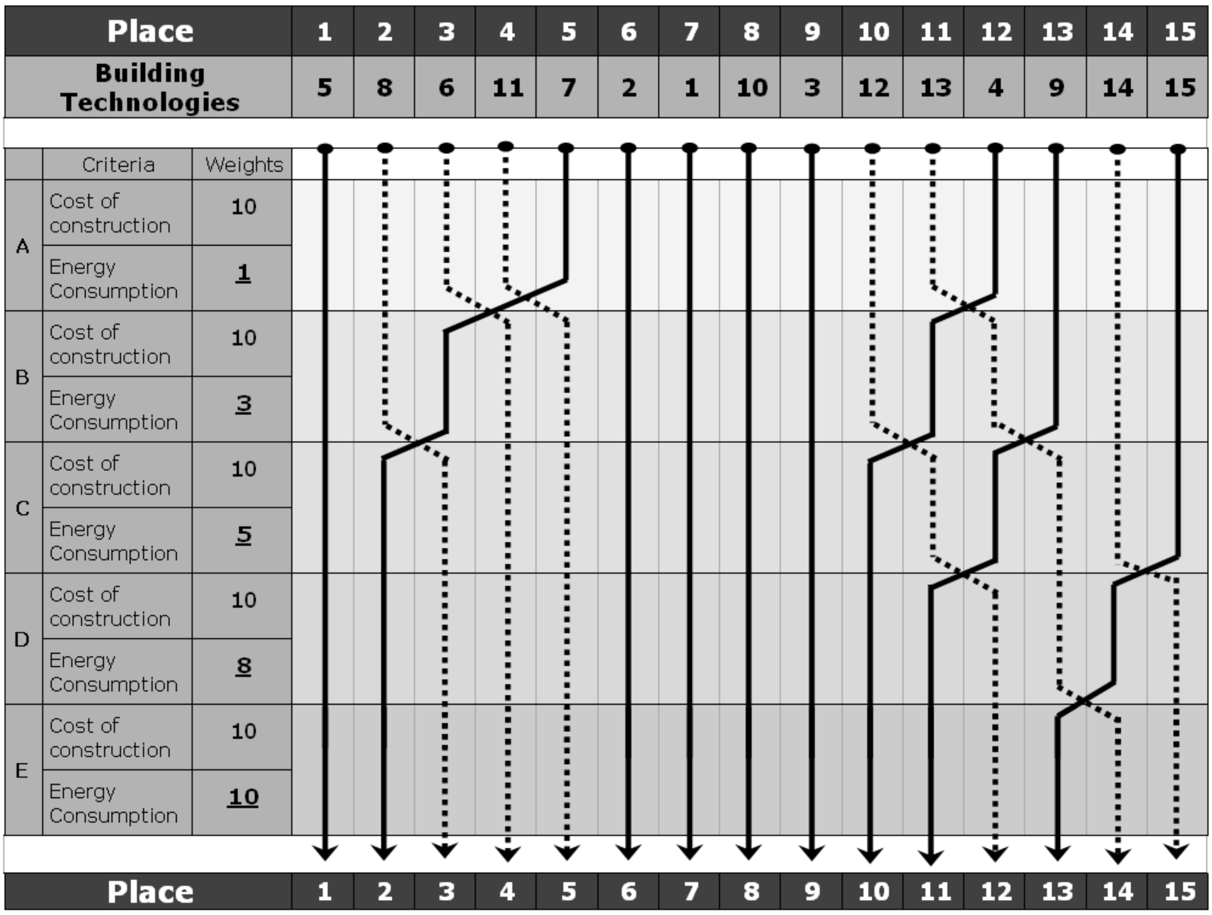

Figure 6 Evaluative comparison with changing weights of criteria – Cost of Construction and Energy Consumption

CONCLUSIONS

Decision making means the action of an individual aimed at selecting an action which achieves the required objective in the best manner. In this work, main stages and important points are identified in the evaluation process and the selection of building technologies suitable for the building's envelope. A computerized tool that enables the designer, which usually does not have enough resources (money or time), to take appropriate measures in the process of selecting technologies for building envelope, has been presented.

The MCDM process described in this work assures that the various issues affecting the design quality and building are taken into consideration. The suggested evaluation system assists in avoiding cogent negative consequences regarding the investor and the future managers of the project, with relation to the maintenance cost and the functional compatibility of selected building technologies. Moreover, a system based on the MCDM approach enables to solve integration problems of different areas related to design and maintaining a building within their common evaluation time. Hence, enabling to reflect the real costs and benefits of a certain building technology. This is due to equal consideration of materialized values as well as those which are difficult to define in financial terms, but impact the social and ecological environment and the individual himself.

Testing the developed computerized system has conformed its efficiency in the process of selection and design, and proved that multi-criteria evaluation helps in finding compromises between social, political, environmental and economical influences, and based on this, infer objectives for viable development, and thus, finding an optimal design solution.

Future development work will include support in the problem in hand analysis, so the tool can suggest suitable technologies. Hence it can cover and assist the whole design process. Additionally, integration of simulation performance tools in the computerized tool. Moreover, evaluation of technologies for the different aspects of the building (Construction, Mechanical systems, etc) will be included.

REFERENCES

Kirk S. and Spreckelmeyer K. 1988. “Creative Design Decisions. A Systematic Approach to Problem Solving in Architecture.” New York.

Maguire C., Kazlauskas E.J. and Weir D. 1994. “Information Services for Innovative Organisations.” Academic Press, San Diego.

Schmoldt D. and Peterson L. 2000. “Analytical Group Decision Making in Natural Resources: Methodology and Application.”

Vincke F., 1992. “Multicriteria Decision-Aid”. John Wiley & Sons.

Youdale J. 1983. “A comparative Study of Three Multiple Criteria Decision Methods to Ranking Decisions.” Simon Fraser University.

Zeleny M. 1973. “Compromise Programming, Multiple Criteria Decision Making.” University of South Caroline Press. USA.