MULTI-CRITERIA DECISION FRAMEWORK FOR SEISMIC RETROFITTING OF LOW-RISE BUILDINGS

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A thesis submitted in the fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

NOVEMBER 2014

To researchers who have been devoted

their efforts on saving people's life

from natural disasters

ACKNOWLEDGEMENT

I was in contact with many retrofit designers, researchers, and organizations within the preparation of this thesis. They have contributed towards filling out the questioners, sending their criticism and comments. In particular, I would like to offer my sincere appreciation to my thesis supervisor, Professor Wahid Bin Omar, for encouragement, guidance, critics and friendship. I am also very grateful to my Iranian co-supervisor Associate Professor Abdoreza Sarvghad Moghadam the manager of structural engineering of International Institute of Earthquake Engineering and Seismology (www.iiees.ac.ir) for his guidance, advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here. I am also indebted to Universiti Teknologi Malaysia (UTM) for cooperation my PhD study. Librarians at UTM and IIEES in Iran also deserve special thanks for their assistance in supplying the relevant literatures.

My sincere appreciation also extends to all Iranian consultant engineering companies and university professors who have provided assistance at various occasions. Their views and tips are useful indeed, however it is not possible to list all of them in this limited space.

ABSTRACT

Among different types of old buildings in earthquake prone area, many conventional low-rise buildings are vulnerable due to non-compliance with current codes and other potential weaknesses. Therefore, decision making for selecting an appropriate alternative is still an unresolved problem among retrofit designers. It is clear that selected alternative, should comply the current codes in terms of structural criteria, but the other criteria may not be considered. The main goal of this study is to introduce a new methodology for making decision in order to find the best alternative considering all effective criteria in retrofitting of low-rise buildings. Among several engineering algorithms which have been studied in this research, Analytic Hierarchy Process (AHP), as a technique of Multi-Criteria Decision Making (MCDM), found compatible to solve the problem. Considering four main criteria and nineteen sub-criteria under a hierarchy pattern can satisfy all involved parties in retrofitting projects. Using Matrix of Pair-Wise Comparison (MPC) as a technique of AHP for determining the weight of the criteria will be difficult when the number of judgment becomes large. For solving this problem, default weights as a reliable method for determining the weight were provided through the questionnaires. Besides the quantitative method, in order to score the alternatives, verbal rating was proposed as a qualitative method which is the focus of this research. Based on the above framework, a computer program was developed and using qualitative and quantitative methods, solving MPCs, calculating Consistency Ratio (CR), and normalization of the results are the capability of the program. The program was also evaluated through two case studies and the results verify that the program can help decision makers to select an appropriate alternative. Fuzzy AHP proposed as a developed method and the first case study was also evaluated by Triangular Fuzzy Numbers (TFN) and the results conclusion with AHP.

ABSTRAK

Kebanyakan bangunan lama yang terletak di kawasan gempa bumi terdedah kepada risiko kerana tidak menepati spesifikasi semasa dan mempunyai beberapa kelemahan yang lain. Oleh itu, keputusan untuk memilih alternatif yang sesuai terus menjadi masalah yang masih belum selesai di kalangan pereka bentuk naik taraf. Jelas bahawa alternatif yang dipilih hendaklah mematuhi spesifikasi semasa dari segi kriteria struktur bangunan, tetapi kriteria lain tidak pula dipertimbangkan. Objektif utama kajian ini adalah untuk memperkenalkan metodologi baharu dalam membuat keputusan semasa memilih alternatif yang paling sesuai selepas mengambil kira semua kriteria dalam projek penambahbaikan. Daripada beberapa algoritma kejuruteraan yang digunakan dalam kajian ini, Proses Analisis Berhierarki AHP yang digunakan sebagai Pembuat Keputusan Pelbagai Kriteria MCDM didapati sesuai untuk menyelesaikan masalah tersebut. Sebanyak empat kriteria utama dan sembilan belas kriteria sampingan dianalisis oleh algoritma ini, dan hasil analisis didapati berupaya untuk meyakinkan semua pihak yang terlibat dalam projek naik taraf bangunan. Matriks Bandingan Pasangan Demi Pasangan (MPC) digunakan untuk menentukan pemberat kepada sesuatu kriteria sebelum disusun dalam AHP. Kaedah ini menghadapi kesukaran pada bilangan pengadilan yang besar. Untuk menyelesaikan masalah ini, pemberat ditentukan melalui soal jawab. Selain kaedah kuantitatif untuk memberi skor kepada alternatif, skor lisan juga dicadangkan sebagai kaedah kualitatif yang juga merupakan fokus utama kajian ini. Berdasarkan rangka kerja di atas, sebuah program komputer telah dibangunkan dengan fungsi-fungsi seperti penggunaan kaedah kualitatif dan kuantitatif, menyelesaikan MPC, mengira Kadar Konsistensi (CR), dan menormalisasikan keputusan. Program ini kemudiannya diuji dengan menggunakan dua kajian kes. Hasil ujian mendapati bahawa program ini boleh membantu pembuat keputusan untuk memilih alternatif yang sesuai. AHP Kabur dan Nombor Kabur Tiga Penjuru (TFN) digunakan untuk menilai kajian kes pertama dan kesimpulan dengan AHP.

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LIST OF ABBREVIATIONS

AI	-	Artificial Intelligent
AHP	-	Analytic Hierarchy Process
ANN	-	Artificial Neural Networks
ASCE	-	American Society of Civil Engineering
BNP	-	Best Non-fuzzy Performance
BSO	-	Basic safety objective
CBF	-	Concentric Braced Frame
CI	-	Consistency Index
CMU	-	Concrete Masonry Unit
COA	-	Center Of Area
CR	-	Consistency Ratio
DBS	-	Division by Sum
DBM	-	Division by Maximum
DCR	-	Demand Capacity Ratio
EBF	-	Eccentrically Braced Frame
HP	-	Fuzzy Analytic Hierarchy Process
FLS	-	Fuzzy Logic System (FLS)
FRP	-	Fiber Reinforced Polymer
FEMA	-	Federal Emergency Management Agency (USA)
GAs	-	Genetic Algorithms
GSDMA	-	Gujarat State Disaster Management Authority(India)
IITK	-	Indian Institute of Technology Kanpur
IRSCE	-	Iranian Society of Consulting Engineers
MCDA	-	Multi-Criteria Decision Making
MPOR	-	Management and Planning Organization of Iran
MPC	-	Matrix of Pair-wise Comparison
NBS	-	New Building Standard

NCIC	-	Non-Traditional Capital Investment Criteria
NSP	-	Nonlinear Static Procedure
NDP	-	Nonlinear Dynamic Procedure
NZSEE	-	New Zealand Society for Earthquake Engineering
RCI	-	Random Consistency Index
TIPS	-	Theory of Inventive Problem Solving(TRIZ)
TFN	-	Triangular Fuzzy Number

LIST OF SYMBOLS

a_i	-	Geometric mean of criterion i
a_{ij}	-	The comparison value of criterion" i" to criterion" j"
Di	-	Alternatives scores
Xij	-	Performance of each alternative with regard to each criterion
Wj	-	Criterion weights
W_A	-	Weight of the architectural criteria
W_E	-	Weight of the economic criteria
W_O	-	Weight of the operational criteria
W_S	-	Weight of the structural criteria
W_{Ae}	-	Weight of the aesthetic criterion
W_{Av}	-	Weight of the availability criterion
W_B	-	Weight of the base shear reduction criterion
W_C	-	Weight of the compatibility criterion
W_{Co}	-	Weight of the cost of operation criterion
W_{Cm}	-	Weight of the cost of maintenance criterion
W_D	-	Weight of the ductility criterion
W_{DI}	-	Weight of the disruption criterion
V_{Dt}	-	Weight of the down time criterion
W_{Du}	-	Weight of the durability criterion
W_F	-	Weight of the foundation changes criterion
W_P	-	Weight of the phased construction criterion
W_Q	-	Weight of the quality assurance criterion
W_R	-	Weight of the rate of demolition criterion
W_{St}	-	Weight of the strength criterion
W_V	-	Weight of the vulnerability (during operation) criterion
W_θ	-	Weight of the stability(drift) criterion
W_β	-	Weight of the Torsional strength criterion

W_{γ}	-	Weight of the Stiffness irregularity criterion
S_A	-	Score of an alternative with respect to the architectural criteria
S_E	-	Score of an alternative with respect to the economic criteria
S_O	-	Score of an alternative with respect to the operational criteria
S_S	-	Score of an alternative with respect to the structural criteria
S_{Ae}	-	Score of an alternative with respect to the aesthetic criterion
S_{Av}	-	Score of an alternative with respect to the availability criterion
S_B	-	Score of an alternative with respect to the base shear reduction criterion
S_C	-	Score of an alternative with respect to the compatibility criterion
S_{Co}	-	Score of an alternative with respect to the cost of operation criterion
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S_{St}	-	Score of an alternative with respect to the strength criterion
S_V	-	Score of an alternative with respect to the vulnerability criterion
S_{θ}	-	Score of an alternative with respect to the stability(drift) criterion
S_{β}	-	Score of an alternative with respect to the Torsional strength criterion
S_{γ}	-	Score of an alternative with respect to the Stiffness irregularity criterion
λ_{max}	-	Largest eigenvalue
θ	-	Stability Coefficient
β	-	Torsional Stiffness Irregularity
λ	-	Vertical Stiffness Irregularity

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CHAPTER 1

INTRODUCTION

1.1 Earthquake and irreversible damages

Earthquake as the most hazardous catastrophes the unplanned release of kinetic energy in the earth's crust that results in seismic tremors or waves. Earthquakes are created by the interaction of the tectonic plates that constitutes the earth's crust. These plates are just like a group of float rafts that are close together. When plates meet plate boundaries and fractures in the crust called faults are made, however, not all faults cause earthquakes. This is because earthquakes are created by stress in the crust. Most faults and boundaries go by smoothly. The ones that cause earthquakes are irregular in shape and experience a lot of friction. This strike slip phenomena cause the opposite sides of a fault to catch and lock. This causes a buildup in pressure and stress until the sides of the fault suddenly slip past each other. This is what causes the release of energy that creates an earthquake (Universe Today, 2009). The measurement of an earthquake is made in magnitudes. The system of magnitudes universally used is the Richter scale that was introduced by Richter and Gutenberg in 1935. The Richter varies from 1 to 10 with 10 identified to be the strongest earthquake. The magnitude of an earthquake is derived from released moment energy, the epicenter of occurrence, and how far induced fault slipped.

The 1971 earthquake in San Fernando, the 1989 Loma Prieta earthquake in San Francisco, the 1994 Northridge earthquake in San Francisco and the 1995 Kobe earthquake led to considerable impacts in the requirements of seismic design, particularly in the high risk seismic areas of North America (Jianhua Liu, 2006). Recent earthquake revealed the huge power of nature and the disastrous impact of such power upon urban areas. Damages and fatalities associated with older buildings that were constructed by older codes, are far worse than newer buildings that have been built by more stringent code requirements. Based on a general scale, the number of older buildings constructed before 1980's is believed to be many times more than the stock of newer buildings (Moe Cheung et al, 2002). Specifications of the most devastated earthquakes that occurred in the last decade have been collected in Table 1.1.

Table 1.1 Specifications of the most devastated earthquakes in the last decade (Collected from IIEES 2011)

Location	Date	Magnitude	Deaths	Injured	Destroyed home	Damaged home
Turkey	2011	7.1	534	2300	14,618	
Haiti	2010	7	316,000	300,000	97,294	188,383
china	2008	7.9	87,587	374,177	5,360,000	21,000,000
Indonesia	2006	6.3	5,749	38,568	127,000	451,000
Pakistan	2005	7.6	86,000	69,000	32,335	About 80%
Iran	2003	6.6	31,000	30,000	About 85%	About 85%

Among different types of old buildings in earthquake prone area, many conventional low-rise buildings are vulnerable due to weakness of their construction technology, quality control, and lack of sufficient supervision in construction especially in countryside. Therefore, seismic retrofitting of these types of vulnerable buildings are the responsibilities of structural engineers and of course grave concern for policy-makers. On the other hand, researchers are still entangled with proposing an appropriate methodology for decision making on selecting the best retrofitting alternative considering the effective criteria. Decision-making is one of the most important aspects in our life that is taken based on some criteria, which are related to the problem. Sometimes, it is perceived there would be a better choice in applying a suitable method that might be missed in decided option. It should be emphasized that effective criteria play an important role in selection of an appropriate alternative. Civil engineers also face these problems in all engineering aspects and retrofitting of buildings. It is clear that selected alternative must comply with the current codes in terms of structural criteria, but the other economic, operational and architectural criteria might not be considered. Having an appropriate method considering all of effective criteria can help designers to select the best alternative for retrofitting of large numbers of low-rise buildings in earthquake prone areas in order to save human life and national resources.

1.2 Necessity of the Research

According to codes such as FEMA 356(2000), ASCE /SEI 41-06(2007), NZSEE (2006), BS EN 1998-3(2005) and IRI 360 (2007), all the old buildings which do not meet the criteria of the codes, should be evaluated with regard to their resistances against earthquake. They probably need to be retrofitted (or rehabilitated) due to some deficiencies related to their gravitational and lateral resistances, material and construction weaknesses. Although some alternatives have been proposed in codes and researches to retrofit vulnerable buildings, decision making of selection an appropriate alternative is still an unsolved problem among retrofit designers and a few patterns are available to come up with this problem. Researches such as Bostenaru Dan M. D. (2004) and Giovinazzi S. and Pampanin S. (2008) proposed methods which were based on analysis and design all of screened alternatives, and the best alternative was selected through a comparison method with respect to some criteria. These approaches are time-consuming process and lots of budget should be allocated for this purpose, however it is beneficial in high-rise and important buildings. Besides, Moghadam A.S. and Azmoodeh B.M. (2011) proposed a binary approach procedure to optimize the limited seismic retrofitting alternative for specific vulnerable buildings. In some countries such as Iran, after evaluating of a low-rise building and selecting some appropriate alternatives by screening, the best alternative is selected directly by retrofit designer or just through a simple comparison in respect of some criteria (without designing) and then detailed design is just fulfilled for the best selected alternative. It is clear that requirements of current codes should be satisfied by selected seismic retrofitting alternative. Does the selected alternative satisfy the other economic, operational, and architectural criteria? Having an appropriate method considering all of effective criteria can help designers to select the best alternative for seismic retrofitting of large numbers of low-rise buildings in earthquake prone areas. As a matter of simplicity, the word ‘retrofitting’ that means same as ‘rehabilitation’, 'strengthening' or improving the seismic performance, is used in the study.

1.3 Problem Statement

Many problems are involved for selecting the best seismic retrofitting alternative in low-rise buildings. Finding an appropriate framework among different engineering algorithms is the first problem of this research. This framework should satisfy all of the involved groups including structural engineers, architects, contractors, owners, and authorities. On the other hand, the framework should be applicable so that companies and retrofit designers can easily use it. Available algorithms are based on analysis and design all of screened alternatives that are time-consuming process and lots of budget should be allocated for this purpose. Having a qualitative method especially for low-rise building can help companies and retrofit designers to use it.

The second problem is related to complex and incommensurable criteria. Many quantitative and qualitative criteria are involved into decision making for retrofitting of buildings as mentioned in Section 3.3. Structural criteria are among the important ones which according to codes such as FEMA 547(2006), NZSEE (2006), BS EN 1998-3(2005). The target of retrofitting of a building is to reach to a certain performance level. These criteria are fundamentally extracted from the analysis of the retrofitting alternatives. Since there are four common procedures for analysis of buildings, the output of analysis are different. Comparison the structural criteria among some nominated alternatives are difficult when each of them needs to be analyzed with different methods. Although designers are allowed to use Nonlinear Static Procedure (NSP) or Nonlinear Dynamic Procedure (NDP) for most of buildings, these methods are time consuming and also are sensitive respects to some parameters (Pashaei and Torabi, 2007). Operational criteria are not commensurate with structural criteria and cannot be extracted from analyzing and designing of retrofitting buildings, however have a great influence on selecting the best alternative. Criteria such as down time and rate of demolition can be evaluated quantitative and the other criteria such as availability, vulnerability, and possibility of phased work are qualitative and should be judged by designer (decision maker). Disruption and aesthetic are two sub criteria of architectural criteria and both of them are qualitative. Cost of operation and maintenance as economic criteria can be scored after designing, analyzing, and estimating cost of the all nominated alternatives. The procedure of retrofitting is based on some tests and inspections and it is quite different respect to new building, estimating the cost of retrofitting is difficult and can be changed during operation. Economic criteria are evaluated by monetary value and are not commensurate and equivalent with the other non-monetary criteria.

Different extensive codes and guidelines have different instructions and viewpoints in terms of retrofitting objectives, procedures, and retrofitting methods; however, there are some similar aspects among them. FEMA 356(2000) & ASCE/SEI41-06(2007) consider four Target building performance levels as a parameter of retrofitting objective that include Operational, Immediately Occupancy, Life Safety, and Collapse Prevention**.** BS EN 1998-3(2005) consider three Limit States (LS); Near Collapse (NC) for heavily damaged, Significant Damage (SD) for significantly damaged, and Damage Limitation (DL) for slightly damaged. On the other hand, NZSEE (2006) expected performance level should be set at as nearly as is reasonably practicable to New Building Standard. Thus the initial target level for improvement should be 100% NBS (Percentage of New Building Standard). In many cases, this will not be practicable and it will be necessary to establish a reasoned reduction to an acceptable level. In any event NZSEE (2006) recommends that 67%NBS be regarded as a minimum to be achieved in the structural improvement measures notwithstanding that the legal minimum requirement is possibly only 34%NBS. This viewpoint is simple and easy to use but completely different with FEMA 356(2000), ASCE/SEI41-06(2007) and BS EN 1998-3(2005).

Different usage of buildings is the last involved problem in this research. Weighting the Criteria is varied respect to occupancy of buildings such as residential, educational, and historical buildings. For example down time is an essential criterion in a school or college because the operation of retrofitting can be performed just during the holiday seasons and rate of demolition and possibility of phased work are the important criteria for medical center in order to remain at service during the operation of retrofitting. According to the codes such as BS EN 1998-3(2005), FEMA356 (2000) and NZSEE (2006) performance level of building is also varied for different usage (such as life safety for emergency buildings), although this parameter cannot effect on comparison among some alternatives for a specific usage.

1.4 Research Objectives

The main goal of this study is to introduce an appropriate methodology for making decision in order to find the best seismic retrofitting alternative not only by allocating less time and budget but by also considering all effective criteria in seismic retrofitting of low-rise buildings. The main objectives of this research can be categorized by three objectives; finding appropriate algorithm to solve the problem, developing tools or program, and finding effective criteria for decision making in seismic retrofitting of low-rise buildings.

1.4.1 Finding Appropriate Algorithms

Several algorithms are being used to analyze and solve engineering problems. Genetic Algorithms (GAs), Artificial Neural Networks (ANN), Bargaining methods, and Theory of Inventive Problem Solving (TRIZ or TIPS) are the well-known methods that have been researched in this study but none of them could not help to solve the problem. Analytic Hierarchy Process (AHP), which is a technique of Multi-Criteria Decision Making (MCDM), is used to solve the complex decision-making problem. As a decision method that decomposes a complex multi-criteria decision problem into a hierarchy (Saaty, 1980), AHP is also a measurement theory that prioritizes the hierarchy and consistency of judgmental data provided by a group of decision makers. AHP incorporates the evaluations of all decision makers into a final decision, without having to elicit their utility functions on subjective and objective criteria, by pair-wise comparisons of the alternatives. Weighting the effective criteria and scoring the retrofitting alternatives are the most important positive aspects in AHP method. Matrix of Pair-Wise Comparison (MPC), as main body of AHP is an intermediate step intended to facilitate the development of cardinal weights for the main and sub-criteria.

1.4.2 Developing the Algorithm

Owing to the fact that there are four main criteria, the MPC contains four rows and columns, and only the six (4(4-1)/2) upper elements of the MPC contain judgments. Alternatively, for eight structural sub-criteria twenty-eight (8(8-1)/2) and for six operational sub-criteria nine (6(6-1)/2) judgments are needed. In most cases appraisers face lengthy matrices that make the comparison a bit difficult. According to the questionnaires filled out by eight retrofitting well-known companies of Iranian Society of Consulting Engineers (IRSCE) as mentioned in Section 3.9, considering all of building's usage, the average weights were considered as (recommended) default weights for each main criterion and sub-criterion. Providing default weights can decrease the error of decision maker's judgments in using MPC when the number of judgments becomes large. As a developing method, two verbal ratings for cost and benefit criteria are proposed for scoring the alternatives as a qualitative method that have been emphasize in this study for low-rise buildings. According to IRI-360 (2007) three alternatives should be compared for selecting one of them as the best retrofitting alternatives. Therefor MPC is also considered for scoring the alternatives as another way of qualitative method because three required judgments can be easily done.

Based on methods used for weighting the criteria and scoring the alternatives a computer program was designed. Default (recommended) weights and MPC are two methods that have been considered at the program for weighting the main and sub-criteria. Considering qualitative, quantitative and MPC methods for scoring the alternatives, simplicity and rationality of the process are the program's abilities. In order to present the ability of the computer program, two case studies are applied in selecting the best alternative among some screened alternatives. In the last attempts in this study, Fuzzy AHP (FAHP) known as a fuzzy method to take uncertain (and also certain) data into consideration as a new and developing method for weighting and scoring the retrofitting alternatives. The first case study was also evaluated with this algorithm and the result compare with AHP.

1.4.3 Finding and Categorizing the Effective Criteria

Selecting the best retrofitting alternative depends on accuracy of selecting the effective criteria. According to common codes, article, and guidelines, the effective criteria are categorized into a new hierarchical pattern as main and sub criteria. In this study, structural, operational, financial, and architectural criteria are selected as the main criteria that satisfy the entire involved group including structural and architectural engineers, contractor, owner or client, financers and authorities in retrofitting of low-rise building. For each of main criteria, effective sub criteria are considered. All the sub-criteria are divided to quantitative criteria such as drift and qualitative criteria such as compatibility. Quantitative criteria are evaluated numerically, while qualitative criteria should be evaluated by MPC or verbal rating (More details are provided in Section 3.3).

1.5 Scope of the Research

The scopes of this study are:

i) This research focuses on five common codes, comparing different retrofitting objectives, evaluation procedures and retrofitting methods which consist of FEMA 356(2000), ASCE /SEI 41-06(2007), NZSEE (2006), BS EN 1998-3(2005) and IRI 360 (2007).

ii) The focus of this study is on low-rise buildings because a large number of them are vulnerable in earthquake prone areas; hence, they are extremely needed to be retrofitted.

iii) This research emphasizes on improving qualitative methods for comparing the retrofitting alternatives by proposing Matrix of Pair-wise Comparison (MPC) and Linguistic variable, however the quantitative method is proposed based on Linear Static Procedure (LSP).

iv) Applicability of the algorithm and user friendliness of the computer program is emphasized in this study.

v) Verification from experts through interview and questionnaire.

1.6 Chapters and framework of the research

In Chapter two, first of all, different viewpoints of codes with respect to retrofitting objectives and evaluation procedure are surveyed and classifications of retrofitting methods are compared among codes and researches. Common retrofitting alternatives such as dampers, isolators, shear walls, and fiber-reinforced polymers are studied in this chapter. In order to solve the problem, well-known engineering algorithms including Genetic Algorithms (GAs), Artificial Neural Networks (ANN), Bargaining methods and Theory of Inventive Problem Solving (TRIZ or TIPS) are studied. Since these algorithms were not used in this research, brief definitions and applications of them are summarized. Analytical Hierarchy Procedure (AHP) a subset of MCDA is focused in detailed and Fuzzy AHP is surveyed and compared with AHP. This study is based on these two methods that can solve the problem as the best methods. In Chapter 3 (Research Methodology), AHP, which is a unique technique of MCDM is used to solve the decision-making problem. Structural, operational, economic, and architectural criteria are categorized as the main criteria, and for each of them the effective sub criteria are considered as the hierarchical framework of the selected criteria. Matrix of Pair-wise Comparison (MPC) is considered for weighting the criteria considering occupancy of buildings and also for scoring the alternatives. Default weights have been provided by questionnaires from well-known companies in Iran. Verbal rating is proposed as new method for scoring the alternatives with respect to qualitative criteria. Based on the proposed framework a practical computer program have been developed and proposed in Section 3.8. Fuzzy AHP is also surveyed and considered for both of the weighting the criteria and scoring the alternatives in next part. In the last Section, the steps of comments from expert by questionnaires have been discussed. Although the program surveyed logically, it has been verified with some examples and finally it is run with two different case studies in Chapter 4. The processes of using the computer program are mentioned in this chapter. The first case study is also solved with Fuzzy AHP algorithm in order to consider the uncertainties in some criteria. Results of the case studies are discussed in Chapter 5. In this chapter accuracy, limitations and the other aspects of the program are discussed and also comparison with Fuzzy AHP and other possible solutions are done. Advantages and disadvantages of proposed method are concluded in Chapter 6 and also some directions for future research are proposed.

organizations and engineering associations. For example, residential buildings can be categorized by type of material, structure, building height, and age of building.

vi) Future Research

Every research has its own effort to be done perfectly and deal with subject delicately. Regarding the indefinite range of science followed by limited extend of research time; several cases seem to be missed. It brings the prospective opportunity for eager and persevered researchers to figure out the new aspect of a study. Without a doubt the presented project tried to be carried as much as unique it could be; however, there would be hole in every research project. In this regards, some points have been raised for future works in this field of research so the missing puzzles might be completed. Some of the recommendations are:

1) Using special categories for all classes of buildings at the designed program in order to improve default weights and make them more accurate for specified buildings. Different classes of concrete, steel, and masonry buildings can be practical classes in this manner. On the other hand, special criteria can be considered for each type of buildings.
2) Dividing the main criteria to sub and sub-sub-criteria in order to consider more numbers of criteria. Increasing the number of criteria can increase accuracy of making decisions; despite of the process will be lengthy.
3) Consideration of default scores in qualitative method for all available alternatives for specified buildings in order to decrease the possible errors in scoring the alternatives.
4) Fuzzy Analytic Hierarchy Process (FAHP) can be used for retrofitting of buildings in order to consider imprecise and uncertain criteria with other fuzzy memberships.
5) Bargaining methods can take into consideration in making decisions in order to resolve conflictions among authorities, clients, owner, and consultant engineers in relation with level of retrofit, cost of operation, and other intervention criteria.

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