Financial analysis of retrofitting projects and its role in decision making

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15 WCEE
LISBOA 2012

SUMMARY:

Construction of more than 3000 schools is the primary result of Iranian schools retrofitting program that has been done by state organization of schools. The financial analysis of the project has valuable data that can be effective on revision of seismic evaluation methods and decision making of future projects. The main contribution of this paper is financial analysis of retrofitting masonry buildings and describing outcomes of this evaluation on optimizing of retrofitting projects. In this regard, in the first step, total cost and financial distribution of projects that were retrofitted by Typical Retrofitting Pattern (TRP) and complete retrofitting are compared. In the next step, cost distribution between structural elements is evaluated and compared with their overall seismic performance buildings. Finally, the effect of minor changes of structural details on the total cost of retrofitting is assessed. The results show that the TRP strategy has financially preference on other current methods and could be a useful strategy to deal with a large amount of buildings like schools. Moreover, the detail improvement, considering cost distribution between structural elements and total cost that is dedicated to architectural, electrical and mechanical facilities have considerable effect on total cost of the projects. At last, a simple procedure for prioritizing the retrofitting projects is proposed.

Keywords: Typical Retrofitting Pattern, School retrofitting, financial evaluation, decision making

1. INTRODUCTION

Iran is one of the most earthquake prone countries and considering the seismicity of this region, it necessitates the structural safety as a high priority. Furthermore, large numbers of children who inhabit in schools every day spells catastrophic effects of death of children on society increase importance of schools safety in earthquakes. Regarding this importance, 4 billion dollars was granted by the Iranian Parliament in 2006 according to 4th Development Plan in order to demolish and reconstruct the seismically vulnerable schools and retrofitting the vulnerable ones. According to this law, 132 thousands classrooms should have been demolished and reconstructed and 126 thousands ones should have been retrofitted. According to statistics, The Islamic Republic of Iran has upgraded seismic safety of more than 13 thousands classrooms (equal to 1.2 million m^2) in the form of retrofitting program from 2005 to 2011.
Financial analysis of these retrofitting projects provides structural researchers with new indices to conduct researches in this area. Moreover, future decisions on strategies of school retrofitting depend on financial analysis of retrofitting projects.
In this paper, financial analysis of a number of retrofitted schools is presented in three steps: strategies of retrofitting, structural aspect, and detailing evaluation.

2. FINANCIAL EVALUATION OF DIFFERENT APPROACHES TOWARDS SCHOOL RETROFITTING

Two following different strategies for seismic evaluation and retrofitting of buildings have been used:

2.1. Complete seismic evaluation and retrofitting:

In this approach, each building and each element of the building is evaluated based on current retrofitting codes. Although the accuracy of this approach is very high, it takes lots of time and the final cost of the retrofitting project is much higher than the alternative strategy. As a result, evaluation of large number of school buildings is not practical by this approach. This strategy could be effective in seismic evaluation of complicated, large area or high rise school buildings.

2.2. Typical Retrofitting Pattern (TRP strategy)

Every building is unique and it has its special deficiencies and final plan of retrofitting. However, scattering of architectural and structural plan of school buildings are less than other types of buildings (like residential or other types of state buildings). So, similar defects of school buildings in previous earthquakes led to similar damage in this type of buildings. The TRP strategy is a new approach of retrofitting that could be effective for seismic retrofitting of a large number of buildings. The philosophy of this strategy is based on retrofitting of the similar defects in order to achieve target level of performance for buildings with similar structural plans. At first glance, this approach seems cost effective and time consuming. In this regard, several methods such as: peripheral shotcrete, typical shear walls, shear boxes, center core have been proposed for seismic retrofitting of school buildings with this approach since 2010.
Fig.1 and Fig.2 show the final cost and its distribution between retrofitting stages for 14 school buildings that have been retrofitted with these two approaches in Qazvin province, summer2010. Shear wall and shotcrete are types of the TRP strategy which has been used in this province.

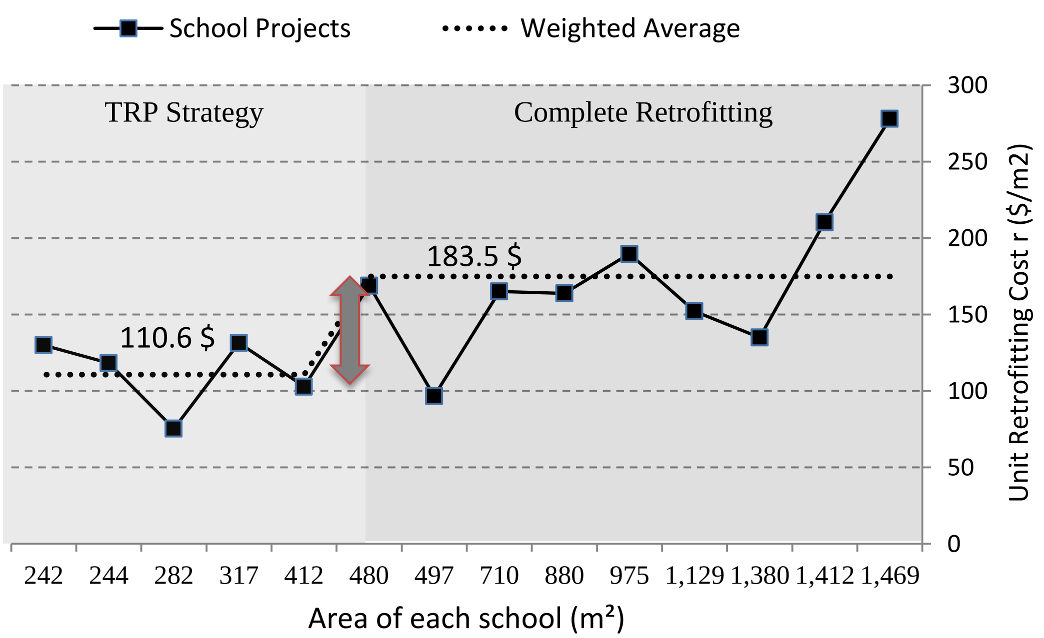


Figure1. Final cost of retrofitting per square meter with respect to square of each school for complete retrofitting and TRP approaches

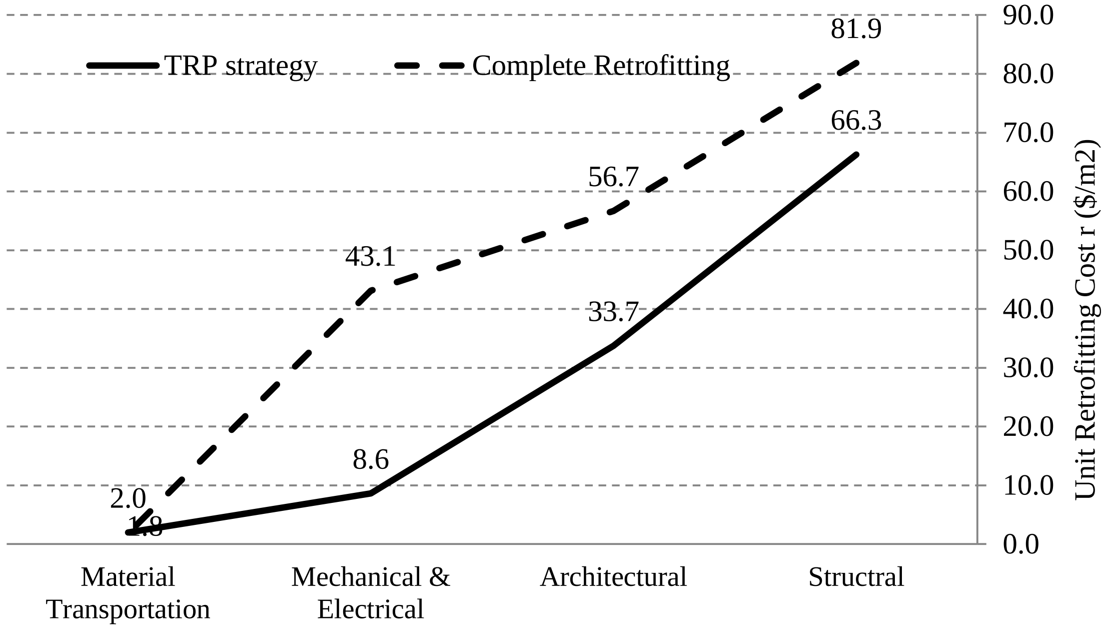


Figure2. Cost distribution between retrofitting stages per square meter for complete retrofitting and TRP strategy

From Fig.1 it is clear that the final cost of TRP strategy is about 60% of complete retrofitting. The most important reason for this difference could be observed in Fig.2. Due to concentration of supplemental structural elements in peripheral of buildings in the TRP strategy, the demolition and reconstruction of parts of buildings like floors, roofs and internal walls is minimized and main portion of architectural and electrical and mechanical facility costs were eliminated. However, complete evaluation and retrofitting of a building leads to seismic evaluation of each element, and many internal elements are retrofitted in this approach. So the high cost of architecture and electrical and mechanical facilities are added to the cost of structural retrofitting. Furthermore, the required time for retrofitting of the building with TRP strategy is much less than the complete retrofitting, and this could be a good suggestion for seismic retrofitting of buildings with time restriction such as schools.

3. COST DISTRIBUTION BETWEEN STRUCTURAL ELEMENTS

As mentioned before, the TRP approach tries to increase seismic performance level of similar buildings to the target level by retrofitting of similar defects; so, financial analysis of buildings which retrofitted by TRP strategy could clarify cost distribution between structural elements. Comparison of cost distribution and seismic performance of each element could be a good index to optimize the TRP strategy. Table 1, 2 was derived from comprehensive data analyses of 8 real projects in Qazvin province. In these tables the average costs for each retrofitting actions are shown based on two TRP methods: Peripheral shotcrete and shear wall.

Table1: Cost distribution between structural element in peripheral shotcrete method

Action		Percentage of Total Cost	Percentage of Total structural part
Foundation		1.26	1.72
Shotcrete	Drilling	2.15	30.23
	Meshing	9.97	
	Shotcrete	9.95	
Slab retrofitting	Diminish	8.28	68.05
	Drilling	1.16	
	Concrete placing	11.95	
	Finishing	13.28	
	Bars	7.89	
	Shear keys	7.12	

Table2: Cost distribution between structural element in shear wall method

Action		Percentage of Total Cost	Percentage of Total structural part
Foundation	Pile	14.62	29.21
	Cap pile	7.76	
Shear wall	Bars	12	23.32
	Concrete placing	5.88	
Slab retrofitting	Diminish	5.48	47.47
	Drilling	0.84	
	Concrete placing	11.08	
	Finishing	8.55	
	Bars	5.83	
	Shear keys	4.59	

Since the life safety is the target performance level of these buildings, the strategy of retrofitting should only provide integrity in jack arch roofs, and it provides higher performance level than life safety for shear wall or peripheral shotcrete as the main lateral resisting system. In these projects the jack arch roofs (the roofs of these evaluated buildings) were retrofitted by reinforced concrete layer (prevailing method of roofs retrofitting). The results of Tables 1, 2 state that the main cost portion of retrofitting was dedicated to the slab retrofitting. So, this distribution does not conform to the seismic performance of each element on the whole of the structure. Consequently, extending of new cost effective methods for roofs retrofitting (like diagonal steel bracing,..) based on TRP approach is essential.

4. FINANCIAL ANALYSIS OF DETAILING

The main aim of this section is to show how minor changes in detailing of retrofitting have major effect in final cost of the project. In this regard, part of retrofitted plan of two story masonry building was financially evaluated with two different details. (Fig.3)

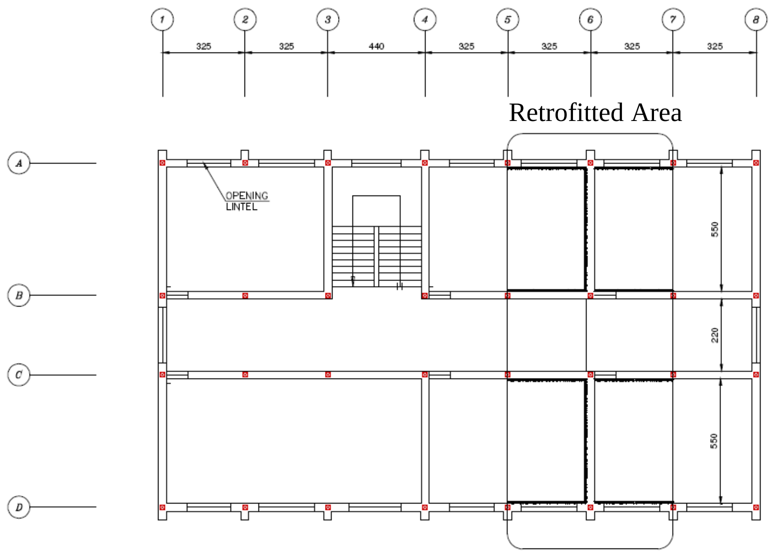


Figure3. Plan of retrofitting

This area was retrofitted by shotcrete (for masonry walls) and tie bracing method (for roofs) with two different details of shotcrete. (Table3, Fig.4)

Table3: Properties of each detail

Detail1: Prevailing detail for shotcrete that consist of:	**Detail2: corrected detail of shotcrete that consist of:**
- Implementation of shotcrete in one side of masonry wall : Thickness: 7 cm, Mesh Ø 6 mm 150/150 - Tie-bracing method for retrofitting of slab - Adding of top and bottom angles in shotcrete: steel Angle 100 X 100 X 10 - Dimensions of shotcrete Foundation are: 40×40cm - Floor reconstruction: In parts of building which coincide with shotcrete. (width: 1m) - Steel tie column	- Implementation of shotcrete in one side of masonry wall : Thickness: 7 cm, Mesh Ø 6 mm 150/150 - Tie-bracing method for retrofitting of slab - Adding only bottom angles in shotcrete: steel Angle 60 X 60 X 6 - Dimensions of shotcrete Foundation are: 20×20cm - Floor reconstruction: In parts of building which coincide with shotcrete. (width: 1m)

Results are shown and compared in Fig.5 and Table 4. It is concluded that elimination of upper angle, steel tie column and reduction of foundation dimensions lead to more than 60% reduction in final cost of retrofitting. Furthermore, construction of real projects with corrected details shows that total time of retrofitting has decreased considerably. Installation of upper angles has many difficulties, and this consumes a large amount of time and money. Furthermore, according to Fig.5, the main portion of retrofitting cost is shifted from secondary structural system (Upper and Lower angles) to main structural system (Shotcrete).

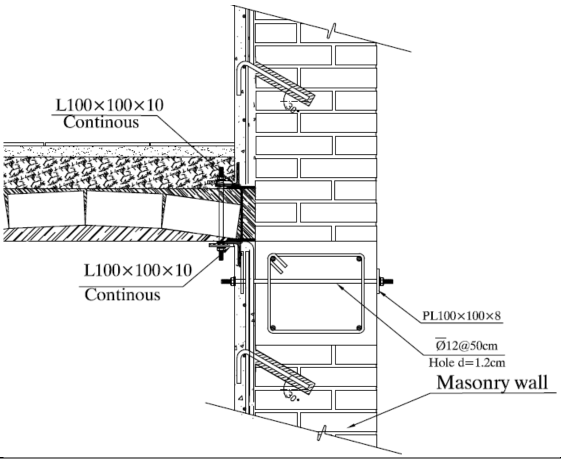
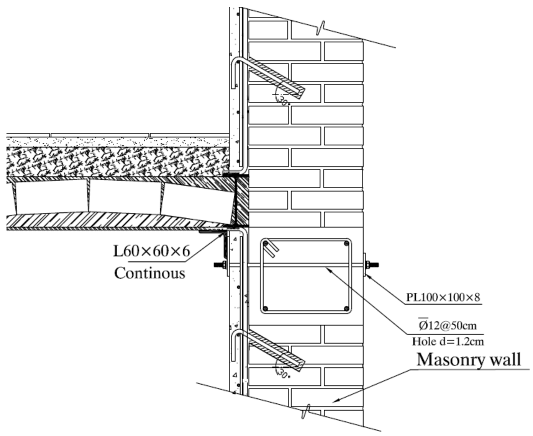
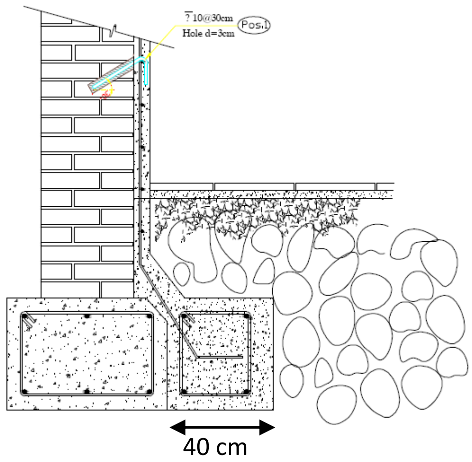
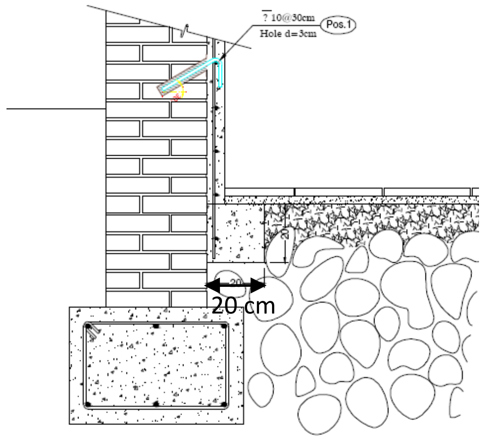
Detail 1	Detail 2
	
Connection between shotcrete and slab	
	
Change in foundation of shotcrete	

Figure4. Schematic difference between the details 1,2

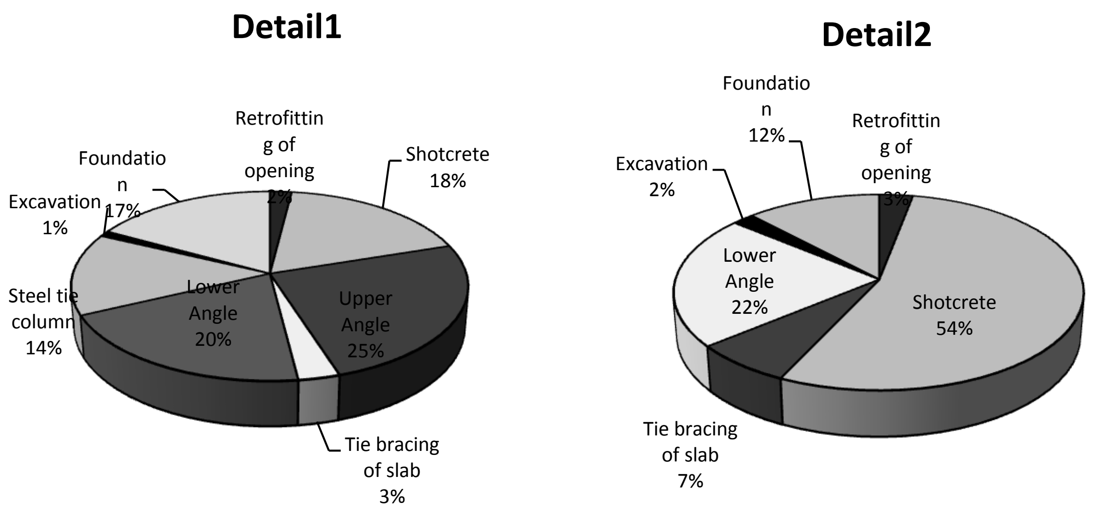


Figure5. Final cost distribution of retrofitting items

Table4. Final cost of two details

Method of retrofitting	Final cost of retrofitting per m2 ($)
1	73
2	27

5. EFFECT OF RECENT STRATEGIES ON TOTAL COST OF RETROFITTING PROJECTS

Based on previous sections three approaches have been implemented in school retrofitting projects: Typical Retrofitting patterns (2010 up to now), modifying retrofitting patterns based on cost distribution and performance level of structural elements, correction of details. Fig.6 shows the variation of school retrofitting cost according to time in recent years. These data is presented based on analyses of 90 schools in different provinces of Iran.

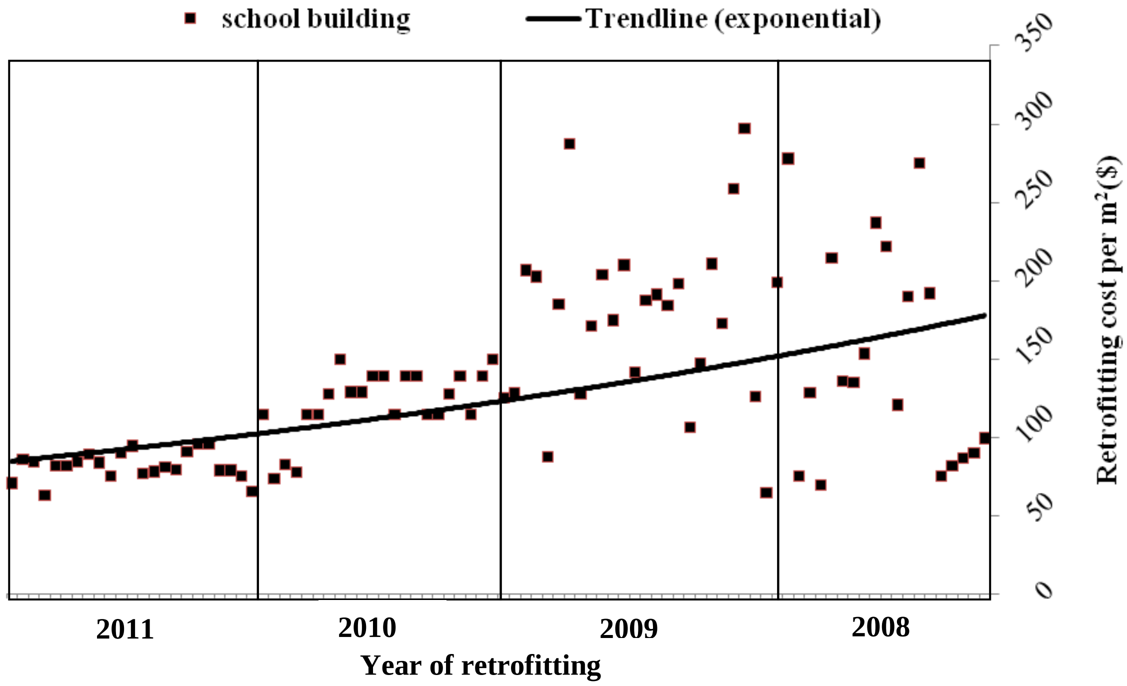


Figure6. Variation of retrofitting cost of schools in recent years

This Fig.6 illustrates the irrefutable effect of these strategies on total cost reduction of retrofitting projects. The average retrofitting cost was about 175US$ (per m^2) in 2008 and following from the new strategies resulted in reduction of 100US$ (per m^2). Furthermore, the variation of total costs in different projects has been decreased by pursuing of these strategies. Accurate estimation of time and cost is the direct result of this reduction, so, it could be helpful in programming of this project.

6. A SIMPLE PROCEDURE OR PRIORITIZING THE RETROFITTING PROJECTS

A brief review of the retrofitting and demolish- reconstruction projects shows the necessity of introducing a procedure in order to prioritize the buildings which are more important and more vulnerable. This fact highlights itself when considering the limited budget and more limited time in case of school buildings. It is noteworthy that the propose procedure should be feasible and simple in order to be implemented easily by engineering community. Fig.7 depicts the proposed procedure. The decision making criteria for school buildings are presented in Table 5. It is worth mentioning that the weighting of each parameter is set as a mutual relative number. For instance criterion E-1 is as important as criterion T-3; so their weighted importance factor would be 1 and 1. However, if the first parameter is slightly more important than the other one, the two numbers would be 3 and 1/3, respectively. The factors 5 and 7 are used for more pronounces relative importance and hence filling the importance matrix. After developing the decision making matrix for the buildings (Table6) this matrix should be normalized in order to each criterion becomes comparable in various buildings. The normalization can be done as:

$$r_{\mathrm{ij}} = \frac{x_{\mathrm{ij}}}{\sqrt{\sum_{\mathrm{i}=1}^{n} {x_{\mathrm{ij}}}^2}}$$

Finally, the weighted decision making matrix is developed:

$$V = [v_{ij}] = [W_j * r_{\mathrm{ij}}]_{n*7}$$

where W_j is the weight of the j-th criterion. In the last step, the maximum of each column of matrix "V" is saved in matrix "A^+" and the Euclidean distance form each matrix "V" lines from the matrix "A^+" yields matrix "C^+". So by arranging the components of matrix "C^+" in descending order, the retrofitting projects are arranged in priority order.

$$A^+ =< Max(v_{1-1}, \dots, v_{n-1}), Max(v_{1-2}, \dots, v_{n-2}), \dots, Max(v_{1-13}, \dots, v_{n-13}) >_{1*7}$$

$$C^+ = \begin{Bmatrix} \sum_{\mathrm{i}=1}^{7} (v_{1i} - \mathrm{A_i})^2 \\ \sum_{\mathrm{i}=1}^{7} (v_{2i} - \mathrm{A_i})^2 \\ \dots \\ \sum_{\mathrm{i}=1}^{7} (v_{ni} - \mathrm{A_i})^2 \end{Bmatrix}_{\mathrm{n}*1}$$

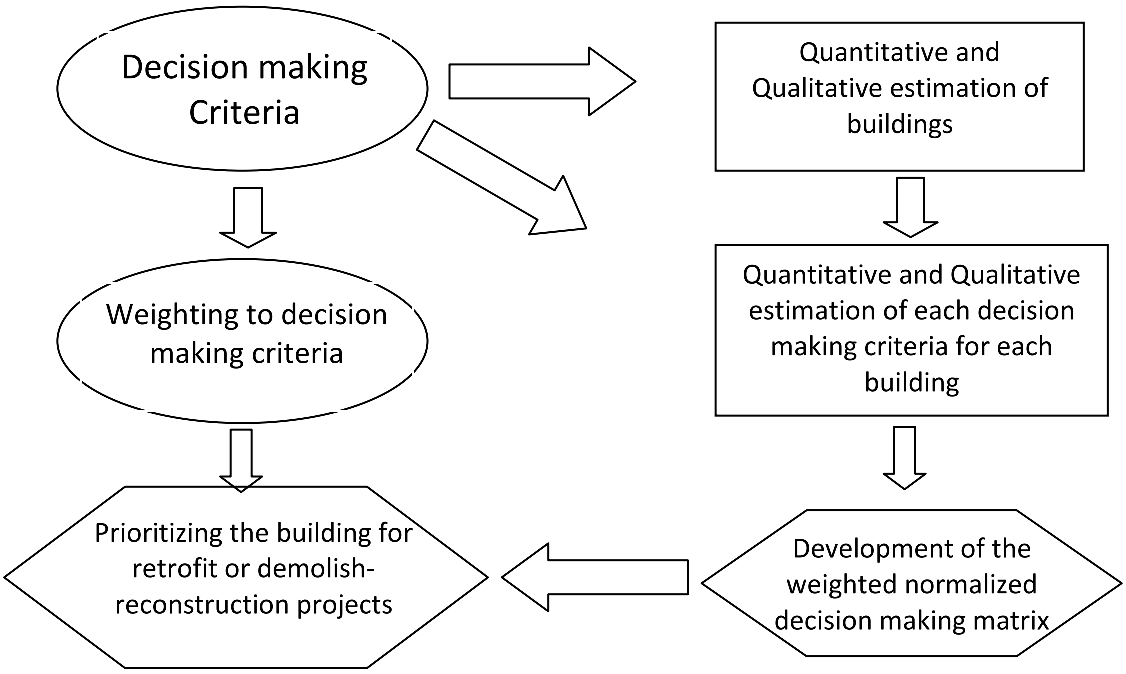


Figure7. Proposed procedure for prioritizing the retrofitting projects

Table5: Decision making criteria

Type of decision making criterion	Criterion Name	Realm	Description
Economical	E-1	Execution cost	
	E-2	Time of disruption	
Social	S-1	Architectural interference	
	S-2	Future of the region	
	S-3	School population	
Technical	T-1	Foundation situation	
	T-2	Seismic code edit	
	T-3	Lateral load bearing system	
	T-4	Seismicity of region	

Table6: A typical decision making matrix

T-n	…	T-1	S-n	…	S-1	E-2	E-1	Building No.
	...	...	...	...	...	E21 Days	E11$	1
	...	...	...	...	...	E22 Days	E12$	2
	...	...	...	...	...	...	...	...
	...	...	...	...	...	E2n Days	E1n$	n

7. CONCLUSION

This paper tries to present several financial analyses and their role on decision making. The Typical Retrofitting Pattern (TRP) approach could reduce the total cost of retrofitting about 40%. The main reason of the reduction is elimination of retrofitting in parts of building with high architectural effect or mechanical and electrical facilities; moreover, Peripheral of buildings is good parts for this purpose. From structural aspect, distribution of cost between structural elements should be in consistent with their roles on total performance level of buildings. Due to high area of roofs to the other structural elements, any cost effective method in this element could considerably reduce total cost of retrofitting. Finally, although some researches provide structural effective seismic retrofitting details, difficulty of their construction is the main cause for increase in total cost and time of construction. In this paper, the current detail of connection between shotcrete and jack arch roofs is investigated in order to show the high cost effect of minor changes in detail.

All in all, financial analysis of current retrofitting projects shows that the TRP strategy besides other related methods like improvement of details has several financial advantages over the complete retrofitting. The financial feedbacks of this project could introduce new indices for researchers to optimize their researches.

AKCNOWLEDGEMENT

This project was supported by the State Organization of Schools Renovation and Mobilization (deputy of Ministry of Education of Islamic Republic of Iran) through its national funding.

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