THE ECONOMIC IMPACT OF SEISMIC RETROFIT ON HERITAGE REINFORCED CONCRETE BUILDINGS

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Abstract. Groups of actors (architects, engineers, inhabitants, investors) put different priorities in interventions on heritage buildings. Seismic retrofit can be done at different levels, from avoiding collapse up to assuring immediate postearthquake functionality. The costs of the retrofit and repair differ depending on the targeted performance between these two poles. Not only an earthquake has impact on a heritage building, but also the retrofit measure. A solution must be found on how much change we accept for retrofit and how much repairable damage we take into account. A developed system counted building elements according to their degree of damage from numerical simulation. Device computations for the retrofit and the repair measures were done considering the material prices and the labor hour prices. Diagrams/tables have been built to see how the total costs vary as addition between the preventive retrofit and the postearthquake repair, compared to costs of rebuilding.

Key words: interwar, historic buildings, skeleton structure, earthquake, cost-benefit analysis

1. Introduction

We have designed a method for assessing the costs and benefits of seismic retrofit measures on a building. To assess the benefits new criteria compared to those of ordinary rehabilitation of existing buildings had to be developed. A multi-criteria decision method is proposed. At the same time the retrofit of residential building should be supported by its users.

Assessing the economic efficiency can be done for individual buildings and classes of buildings. According to recent methods (Glaister and Pinho, 2003) it is possible to switch from single building of a certain class by simplifying the probabilistic method as median inaccuracies resulting from simplification are rectified. In this paper a method was developed for individual buildings. To make the transition to a building class costs were calculated for several example buildings for earthquakes of different intensities. Through this comparison objects were created objects that can be used to design means of economic efficiency. In addition to the structural performance of the building which is reached there are many other factors that measure benefits such as:

– Cost of repair to replacement cost,

– Existing retrofit technologies,
– Relocation need of the residents,
– Duration of the measure,
– Functional or aesthetic restrictions,
– The historical significance of the structural materials.

The ability to create high quality living space through building measures was investigated with regard to factors of cost, structural performance and architectural possibilities of participation. Another aspect of applicability is making priorities. A model chosen for balancing the solution to a problem through multi-criteria decision.

A large part of Romania is affected every 30 years of catastrophic earthquakes. The city of Bucharest, which is located on alluvial soil deposits was affected recently mainly by the effects of the last catastrophic earthquake, on 4 March 1977. Since then the city has been affected by earthquakes in 1986 and 1990, which caused only material damage. The earthquake of 1977 particularly affected interwar buildings. We compared these buildings across Europe. Currently interwar buildings are being retrofitted, following a national strategy, but the number of those retrofitted is very low. Two examples of buildings designed by an important architect of the interwar time, Marcel Iancu: Clara Iancu villa and Jean Juster villa were approached, to see the effects of the 1977 earthquake and contemporary intervention. In 1996 the retrofit of the Telephone Palace, a metal frame building with concrete exterior jacketing was begun. Discussions around it drew attention to the need to alternatives to concrete retrofit. Research on retrofitting existing buildings have resulted in international co-operation such as Sonderforschungsbereich 461 with the University of Karlsruhe, JICA Japan and the European project RISK-UE.

Worldwide methods of survey, alternatives to ATC Rapid Visual screening were reviewed and compared. The next review of state of the art concerned the methods of calculating the economic costs in the overall design of buildings. These methods depend on data availability from country to country. Most developed are in the US or in Germany. The German method based on function spaces was later used in the work to calculate the costs for rebuild. For existing buildings the costs methods were developed in Germany later, since the 1990s. Such, Neddermann developed a method based on building elements, a method we will try to adapt to seismic areas, where unlike at ageing not the whole building is affected, but just some structural elements. For economic efficiency studies are even more rare, and we considered FEMA-274 and ATC-40 as examples of diagrams, to which the curves we aimed to developed can be related. Kappos et al. (1998, 2007, 2008) has scaled engineering-wise the model of economic costs and the statistics from retrofit after the 1999 Athens earthquake in a similar way computer simulation is validated with experimental results. Smith et al (2004) went to a probabilistic assessment of measures in Turkey.

Guidelines for seismic strengthening of historical buildings were reviewed: the Venice Charter (1964), ICOMOS and European recommendations, incorporated in studies about risk threats (Nistor, 2002) or the Eurocode 8. While these are approaches for heritage buildings, for common buildings the performance levels are those to be considered in decision.

For technical decision we built upon the book of Malczewski (1999) regarding spatial problems. For the role of the architect Richter (course work) made a role model in the decision space between goals, resources, benefits and costs. In renovation the model used in Weissenhof was described by Nägele (1992). The ATC-40 considers a series of actors specifically for seismic retrofit. Both the latter employ matrixes (decision tables). At urban planning level there were Fingerhuth and Koch who clarified the moderating role of the architect, among experts, passive public and active affected people. The role of the users were considered also by Ottokar Uhl in the model developed for the Hollabrunn in the 1970s, the glory time of participatism. At regional planning level it was Strassert (1995) developing a method of balancing we will later employ. Also Nägele (1992) employed balancing.

Inclusion of the factor cost into multicriteria decision analysis has been done more recently by the team of Caterino et al (2007 and 2009), with a view to bracing of a reinforced concrete building, but employing passive damping. We did a prefiguration of this system in our work on multi-criteria decision for seismic retrofit at building and urban scale (Bostenaru, 2004).

Other loss estimation approaches refer rather to the large scale. Assessing the economic efficiency can be done for individual buildings and classes of buildings. According to recent methods (Glaister and Pinho, 2003; Crowley et al, 2004, Borzi et al, 2008, Bal et al, 2008) it is possible to switch from single building of a certain class by simplifying the probabilistic method as median inaccuracies resulting from simplification are rectified. Instead of considering statistics, the mechanical characteristics of the buildings are considered, and computations are based on these. We made here reference only to the studies concerning reinforced concrete buildings, which are our subject, but similar studies have been done for masonry buildings.

2. Bucharest case study: problems and potential

The urban framework is based on a holistic approach to disaster management. This takes into account considerations of social sciences and engineering sciences as well as those of the other sectors. Construction and development changed since the 1980s and include many actors with different interests, such as the "public", "experts" and "those affected" we mentioned. The problem we state in retrofit is group multi-criteria analysis and not benefit-cost analysis. In this work the possibilities of the balancing method were analyzed, the relative importance of criteria being permanently taken into account. Seismic strengthening of benefit in the saving of human life and cultural values cannot be assigned a weight. Architecture and planning have changed. Instead of giving equal importance to all sub-areas and investigating them accordingly, a design strategy shall link intervention levels one to another and identify intensive areas while other areas are generally described. Criteria are defined according to which priorities for retrofit of an area or classes of buildings is done. There are three levels on which stakeholders are involved: city, urban zone and building. At each level the problem is different, but there is communication and interfaces with levels above and below (Bostenaru, 2002).

Data was collected typologically for the World Housing Encyclopedia (http://www.worldhousing.net/), and area wide for central Bucharest for EQSIM (Markus et al, 2004). For both the typical construction periods from the history of architecture, as applied for Romania, were used to define structural typologies.

The information includes in case of earthquake safe design, three issues: inventory, evaluation and classification. First we made thus an inventory. In the next chapter a concept that serves as a tool for diagnosis will be developed. The use of similar procedures for the recognition of type of structure as described generated EQSIM database using a questionnaire for surveying a large area. The second step employed, quantitative surveys, involves setting numerical relationships between elements identified in photographs. As the work for EQSIM demonstrated, the type of construction could not be established in the questionnaire but only the type of building elements. The type of construction was determined on computer based on the type of building elements. Such an approach can be employed for developing a taxonomy of building elements, a related one being now followed in frame of the Global Earthquake Model (http://www.globalquakemodel.net/).

The evaluation of the building takes place in three stages: qualitative assessment on site, approximate analytic assessment and detailed analytical assessment. A fourth intermediate stage based on quantitative surveys proposed can be entered. This can be also related to the building class assessment mentioned at the begin.

Both inventory and distribution of buildings in categories influence decision-making aspects. In the typological analysis earthquake resistant features were identified as potentials and seismic deficiencies as problems. It was concluded that the most vulnerable are interwar buildings.

3. Diagnosis: building element method

Interdisciplinarity is an accepted concept in the building engineering. Constructive, economic and building physics questions are involved in an early stage in the so-called integrated design. Interdisciplinarity is an accepted concept in city planning. Different disciplines are integrated through the participatory approach. But interdisciplinarity has not spread as much in disaster management, although there would be structural and economic problems involved in early stages of the intervention, in order to refer to them during the project. Retrofit measures are, in terms of communication costs, a special form of renovation of existing buildings. The building must be properly structured, i.e., returning to our earlier remark, a taxonomy can be created. We have identified elements that could be related to the field of architectural, economic and construction technique data. Such a structuring serves good cooperation of the actors. A building has nodes, they are its joints. Its edges are beams and columns, floors and walls are its surfaces. Dividing a building in the lowest elements is common for structural recognition and costing. The lowest common denominator in this work element is called retrofit element. Building elements may be included in a database, the concept of which we developed.

First we identified the retrofit elements in the building survey. The process of recognition of the structure was divided into vertical and horizontal elements: vertical load bearing elements (frames or walls), horizontal load bearing elements and non load bearing elements. While classic surveys resulted in overlapping plans of levels. For purposes of seismic retrofit survey of structure and damage has to be done. Addition of structural elements, not common in building survey or archive plans is proposed.

Secondly we identified retrofit elements in project management. The instrument characteristic for the field, the so-called "structural plan" which means the project management division (a complex task is subdivided into smaller tasks) was employed. According to it management strategies were described in order to implement technical strategies, guided by selective strengthening (Elnashai and Pinho, 1998). Changing stiffness for high rigidity (to maintain immediate use), strength for high resistance (to limit damage) and of ductility to high (for protection) correspond to different performace levels. These performance levels will later determine certain cost levels, and the recurrence time of earthquakes (size of earthquake converted to time) builds to time vector to which the costs vector relates.

Third we defined retrofit elements in costs calculation. Basic idea is that of tackling economic addition as the vector of costs: retrofit costs for a building and repair costs for a building damaged after a potential earthquake (Fig. 1). We encountered some difficulty to create a family of curves in which costs vary continuously with the measures. It is therefore useful to define levels (Fig. 2). Rough structures, without finishings were considered to red, and building elements were defined for these. The retrofit measure represents an addition to the structural performance and the diagram was abstractly built using the addition of light through windows in a building section.

Fourth and last retrofit elements were considered in the investigation of structures. Examples are given for interwar buildings. They have a reinforced concrete skeleton designed for gravity loads only with brick masonry infill, which limitedly contributes to structural performance. At the scale of building elements we modeled a frame with an opening of 4.5 m and 3 m height and a 3 m high column, in different retrofit settings, for the software SeismoStruct (2003). Images of real damage to which simulation results should be reported were investigated. The description of pathology is based on that by Penelis and Kappos (1997).

Designing interventions on historic buildings differs from the design of new buildings design through a basic condition: all design and construction measures are conducted on the existing building. Some of the most important aspects to consider are:

- Existing buildings are part of existing building stock,
- The design of the intervention on a building involves many actors,
- A survey is needed as pre-project study,
- The data to evaluate the building are other than in a new construction project,
- The structure can be pre-damaged by earlier earthquakes,
- The technology and management must adapt to a particular situation.

Building elements serve all areas and actors responsible for these areas:

- Architect / surveys,
- Inhabitant / project management,
- Investor / cost assessment,
- Engineer / design of structures.

These issues will be detailed in the next chapter.

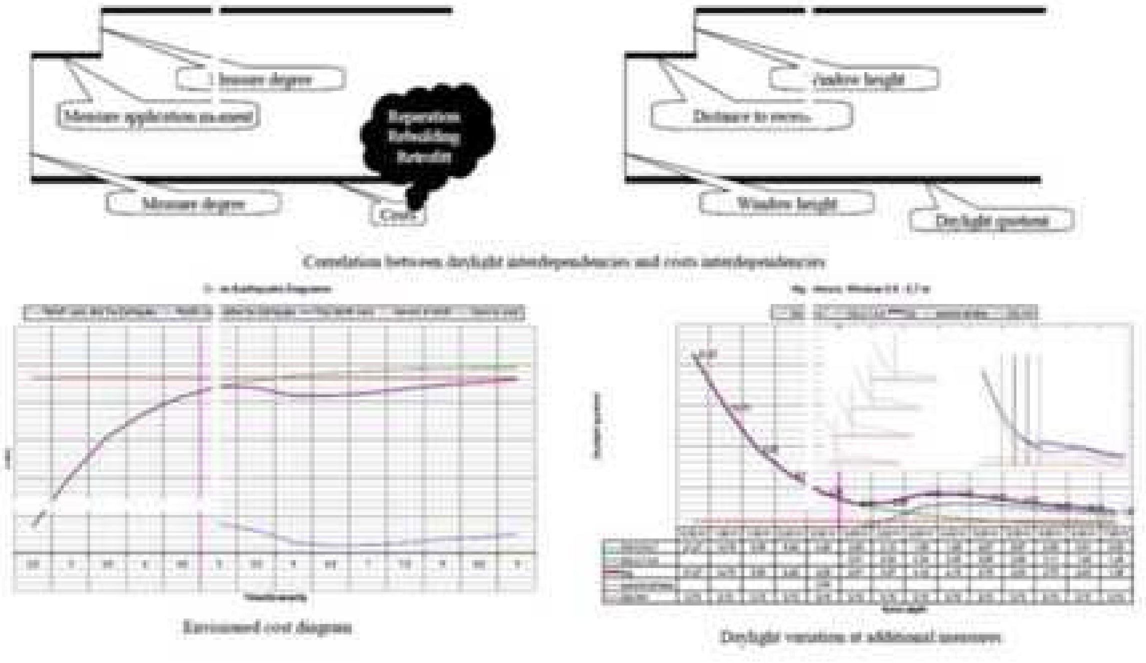


Fig. 1. Correlation between the time and the cost vector, built upon addition principles from light

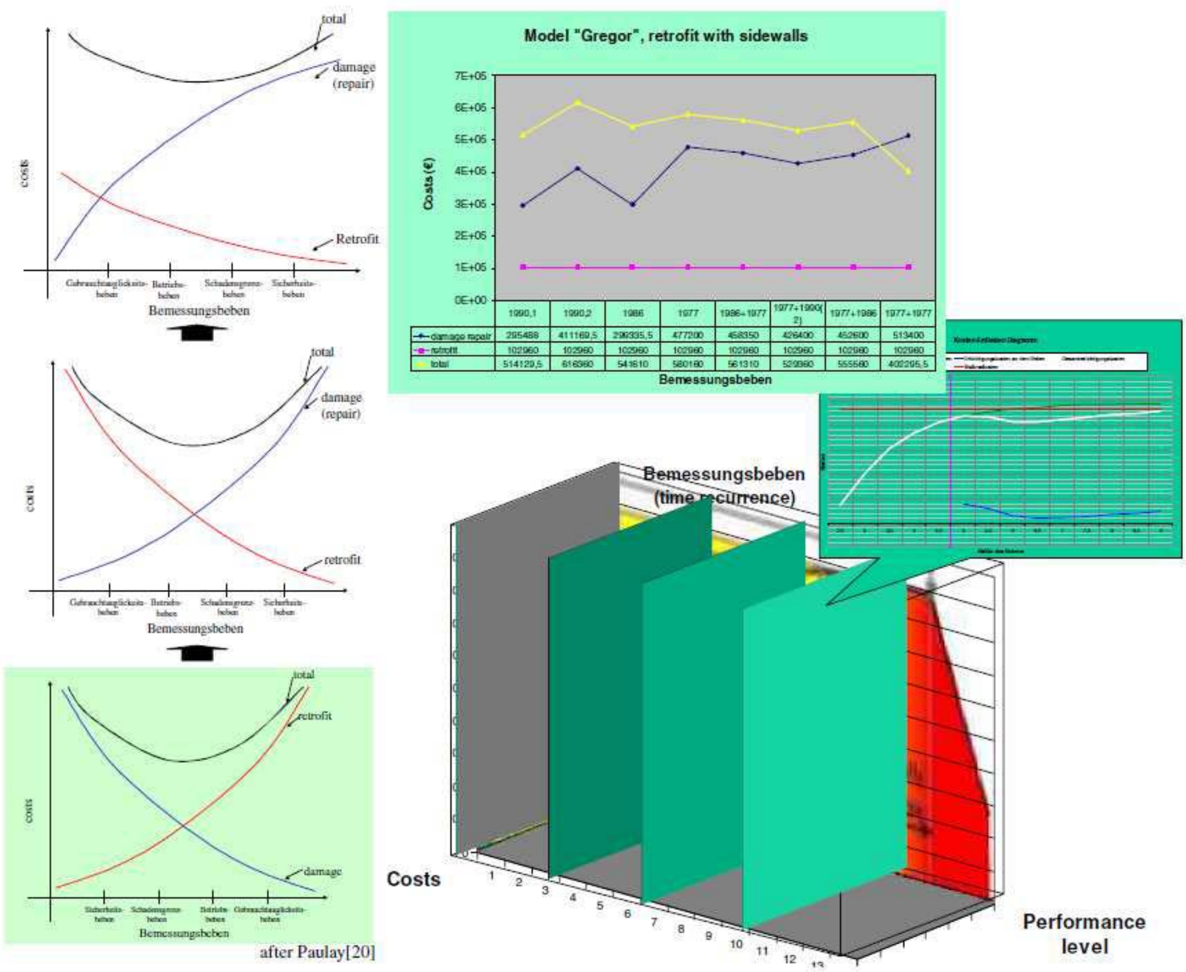


Fig. 2. Development of costs curves in dependance of performance levels

4. Decision-making aspects of benefit-cost analysis

Evaluation of the benefits of retrofit measures is complicated by subjective factors which are gaining momentum to objective factors. State support for retrofit of buildings in Romania is modest: limited to very threatened buildings or those with cultural value. In addition the recurrence period of strong earthquakes is 30 years, making the danger of waning public consciousness. Also many buildings are collective property, which makes it difficult to implement retrofit measures. It is therefore necessary to developed "public ideas" which are the creation of local partnerships that can participate in the retrofit measures. Due to the participatory group decision problem "retrofit of existing buildings" the decision is based on interactivity. Buildings were modelled as spatial decision support systems. This includes identification of corresponding spatial information needs of actors from different fields (such as architects, engineers and economists). Ingredients of a strategic plan for reducing seismic risk are action plans, goals, operational procedures, human resources, time and cost-oriented analysis, evaluation, implementation and communication of priorities. This way to solve a problem in common in urban decision-making since some time. Recognition of potentials and problems builds the begin of the design process while providing weights to elements of planning to order them properly to the goals of the detailed project was part of the recommendations. The mission consists of goals, which can be subdivided into partial goals. Partial goals are referred to in this context as design goals. Each design goal can be achieved by some means. These means are grouped in certain packages. These measures take the form of operations. To run the operations action plans are written. The execution of such operations is a model project itself. For project implementation tools are needed. The whole package of measures to achieve the mission are the recommendations. This scheme is aimed at intelligence-project-selection. The selection phase includes recommendations. The project is not understood as such but as the design of alternative projects, which are assessed according to actors' preferences. These preferences are reflected in the partial goals of the mission and recommendation.

Möller (1984) distinguishes four methods of benefit-cost analysis in construction. Decision trees are a cost-effective, according to this classification. To define the first the goals and then the criteria which actors involved in the decision process, organised in decision trees about retrofit measures use the method of regression, introduced by Joedicke (1976) was employed. The regression consists of two phases: induction and deduction. In induction a database on general knowledge from existing projects is developed. In the deduction phase the hypothesis induced from assumptions in the database (integrated in the mission/ recommendation). Then statements are derived for individual elements in the project based on derived assumptions.

Table 1.

		Goals	Criteria (attributes which measure to which extent goals are achieved)
induction	Database	Storage, configuration, mapping	Reports on building types (WHE)
	assumptions	Minimal intervention in the built substance	Problems and potentials, damage types
deduction	hypothesis	preservation	Building elements
	Assumptions/hypotheses	Appearance of elements	Technical and management strategy
	statements	Change the size, appearance, material	Types of damage (pathology)

These statements build the hypothesis feedback. The actors considered were, as mentioned, structural engineer, architect, investor (all experts) and inhabitant (affected people), all belonging to a larger group of interest participants, at the level of decision makers. Group decision making was simulated as multicriteria decision making, each actor being considered a criterion. Then alternatively the pair-wise method of Strassert (1995) was employed, which does not require weights and instead alternatives are ranked in order of preference of opposite criteria. Table 1 gives an example for the actor "architect".

The actor was chosen for each criterion:

– K1 for the investor (building costs, in this case only, concrete),
– K2 for the structural engineer (so-called equivalent, calculated as the ratio of repair costs on the cost of repair of the damaged item),
– K3 for the architect (influence on the appearance of the building),
– K4 for the inhabitant (measure of disruption to activities inside the building).

The balancing method is to create rankings of alternatives rather than be assigned. Matrix operations are made between different columns but not between different rows of the same columns. Balancing itself means answering questions such as whether an asset has a value to counter two disadvantages that occur simultaneously. Such advantages can be compared in various fields, which sometimes do not have numerical values. It can be applied to buildings where it is difficult to compare the seismic performance of structures with aesthetic changes. K1 and K2 can be calculated quantitatively, K3 and K4 are qualitative classifications.

Modeling the structure, to classify the case studies were considered in two databases: one of interwar buildings in risk category I and interwar buildings showing architectural value (a category of cultural value). The result are 20 buildings in risk category I that have at least architectural value. In the following the common buildings were subject of structural simulation under earthquake loads, modeling first regular (with regard to spans and bays) models, a real interwar buildings, and buildings designed for relocation by the author. First pushover analysis was performed, then dynamic analysis with the accelerogram of the 1977, 1986 and 1990 (for this 2 different) earthquakes, from the European Strong Motion Database (Ambraseys, 2002). For comparison with other locations the 1978 Thessaloniki earthquake was considered. In a later step the relevance of the floor layouts of these buildings will be considered compared to real buildings, in Bucharest but also in Greece, subject of a subsequent research project (Fig. 3).

Results related to retrofit resulted in the relationship between size and impact of earthquakes, later analyzed in interwar buildings. These involved the location and percentage of damaged elements to a certain amount (computed using an algorithm developed in frame of this work Fig. 4) according to the stress-strain relationships for the structural analysis and the costs related to rebuild and no action and the savings, reported to 30% (Fig. 5). Outlooking for the method of repair costs of pre-damaged buildings opposite to retrofit costs the following cases were considered:

- Unretrofitted building,
- Retrofit of a not damaged building,
- Retrofit of damaged buildings.

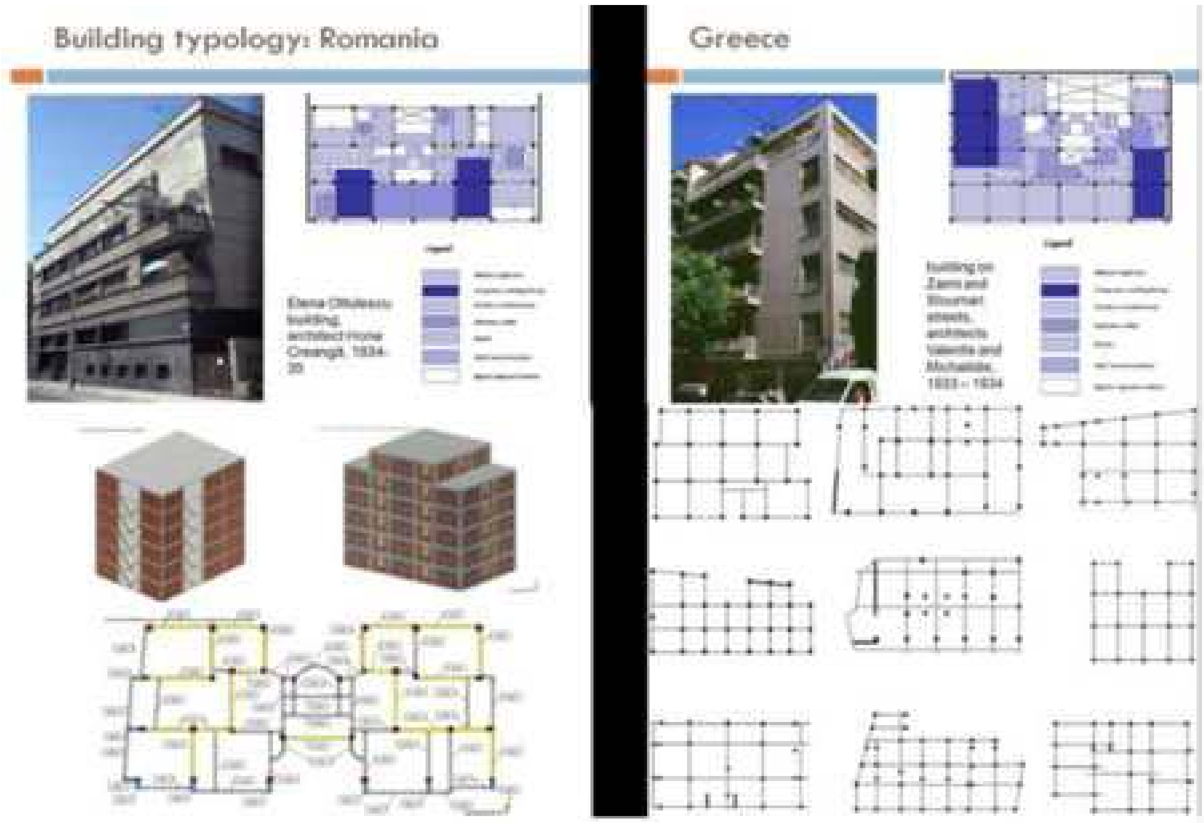


Fig. 3. Relevance of the simple models compared to real buildings in Bucharest and Greece

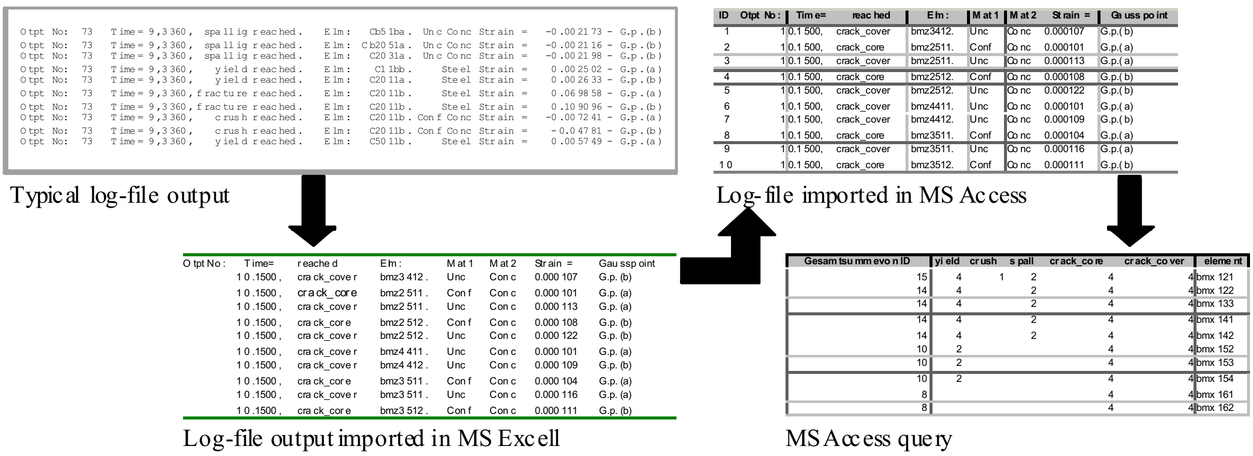


Fig. 4. Algorithm for computation of stress-strain limit achievement

Monuments require a special building concept. In this case values from experience can never be used. In buildings with architectural value there are limitations concerning decoration, construction material conservation, the preservation of spatial sensation, the structural design, the sharing of space, volume and so on. A third category are buildings with environmental value. These are existing buildings that define the urban image. In this case there are restrictions on the volume, façade features, proportion relationships. The last category are buildings without special value, which is relevant only statistically. For the described models some variants of retrofit were investigated. To take into account the structural requirements dynamic seismic analysis for various loads was done. Transferability of the results was investigated by comparing the types with real damage. For this purpose, a matrix was developed for damage suffered by the interwar buildings in earthquakes. To take into account the requirements of the architect relevant buildings with similar style and layout were chosen for which a structure similar to simplified models is possible. To take into account the requirement of the investor costs for these measures were calculated. Alternatives were created regarding "where to do something" ("place":position of the retrofit elements) respectively "what to do" ("action": kind of retrofit elements). These were applied to the regular models. To take into account the requirements of the inhabitant project management plans for selected measures were done so limitations of use can be determined.

5. Conclusions

The concept of retrofit elements was developed to support communication between those who decide on economic efficiency and applicability of the strategy. A building can be subdivided into smaller parts that can be managed. They serve as units for seismic strengthening. They support the typological classification of construction analyzed and a numerical simulation model and distribution of tasks in costs computation. A building element consists of all work to be done to strengthen, repair, rebuild or build new structural element. These are elements that are characteristic for surveying, show typical earthquake damage and define best the seismic behavior. Using stress-strain methods also repair costs can be calculated. The validity of the simulation was analyzed and compared with actual damage. Integrated design means that the relevant actors are involved in the early stages of the design process. Integrated means a difference through the fact that it can support communication processes later in the decision phase (next chapter). An integrated decision support consisting of surveying, aspects of structure and costing uses the same basic elements as building design. In this way the views of stakeholders may be taken to a common denominator. Diagnosis is to be made and potentials and problems shall be put in relationship: the potentials that are mutually supportive and problems that are mutually reinforcing. From the study of pathology a diagnosis can be given. Based on this diagnosis a mission can be made. The mission defined in this paper is economic efficiency and applicability building retrofit.

The decision problem of retrofitting existing buildings features a semi-structured problem, which can be structured in the project but never in assessing vulnerability. It includes a number of soft factors. Spatial expert support systems can be used only at for structural assessment or for costs, but not for both. In case of decision to retrofit existing buildings the project management sets the multi-criteria decision model. It allows to taken into account the need for information of different actors need information as:

visual recognition - elements – local retrofit measures

In frame of the study the structural seismic performance of buildings with reinforced concrete skeleton subjected to cyclic bending was evaluated. The innovative approach is the stressstrain approach, used for building models. Such an analysis allows not only the description of failure mechanisms and the establishment of limit states, eventually reached the buildings, but also to establish the number and position of specific structural members suffering damage of various kinds. In a performance-based approach cost curves were generated, considering the cost structure for rough reinforced concrete skeleton. Regular simplified models can be refined progressively to get some similar to real buildings. Visualization techniques are important to communicate the results of the decision. The World Housing Encyclopedia, based on which the review of typologies was done, is now only an information system experts. It needs weights provided to the criteria to become a tool for collaborative problems. The structuring proposed for the recognition of elements used here can serve the taxonomy which is now being developed. Historical substance is the basis for all subsequent design and construction measures to strengthen old buildings threatened by earthquakes. Passive public sphere actors, experts and those affected are actively involved. Emphasis in choosing the decision factors was on experts with a detailed on between ends and means, benefits and costs. Issues of the affected people, such as owner or tenant have been discussed only in general. For these a second cycle is foreseen. But this procedural dimension is expressed more in operational management, the action plan consisting of mission and measure packages.

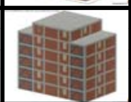
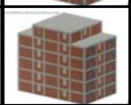
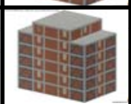
Model	Retrofit	Earthquake 1	Earthquake 2	Reparation (€)	Retrofit (€)	Total (€)	Rebuild (€)	Reparation/ Rebuild	Retrofit/ Rebuild	Total/ Rebuild	Total/ Rebuild-0,30	Reparation/ Retrofit	Retrofit/ Reparation	Difference to not retrofitted (€)	Reparation saving/ retrofit	retrofit/ Reparation saving
		1977	-	506950	0	506950	3123067	0,16	0,00	0,16	-0,14	-	0	-		
		1977	197	526850	0	526850	3123067	0,17	0,00	0,17	-0,13	-	0	-		
		Thessaloniki	-	422000	0	422000	3123067	0,14	0,00	0,14	-0,16	-	0	-		
Özzi		Thessaloniki	Thessaloniki	423050	0	423050	3123067	0,14	0,00	0,14	-0,16	-	0	-		
		1977	-	544400	74785	619185	3123067	0,17	0,02	0,20	-0,10	7	0,1373719	0	0	6236566
		1977	197	595400	74785	670185	3123067	0,19	0,02	0,21	-0,09	8	0,12560507	0	0	3407139
		Thessaloniki	-	422000	74785	496785	3123067	0,14	0,02	0,16	-0,14	6	0,17721626	0	0	-
Özzi Braces 1		Thessaloniki	Thessaloniki	479850	74785	554635	3123067	0,15	0,02	0,18	-0,12	6	0,15585133	0	0	4111961
		1977	-	553050	67987	621037	3123067	0,18	0,02	0,20	-0,10	8	0,1229303	46100	1	1
		1977	197	605250	67987	673237	3123067	0,19	0,02	0,22	-0,08	9	0,11232813	78400	1	1
		Thessaloniki	-		67987	67987	3123067	0,00	0,02	0,02	-0,28	0	-	-422000	-6	-0
Özzi Braces 2		Thessaloniki	Thessaloniki	478800	67987	546787	3123067	0,15	0,02	0,18	-0,12	7	0,14199373	55750	1	1
		1977	-	580950	67987	648937	3123067	0,19	0,02	0,21	-0,09	9	0,11702659	74000	1	1
		1977	197	606650	67987	674637	3123067	0,19	0,02	0,22	-0,08	9	0,1120689	79800	1	1
		Thessaloniki	-	473900	67987	541887	3123067	0,15	0,02	0,17	-0,13	7	0,14346191	51900	1	1
Özzi Braces 3		Thessaloniki	Thessaloniki	476700	67987	544687	3123067	0,15	0,02	0,17	-0,13	7	0,14261926	53650	1	1
		1977	-	455100	135973	591073	3123067	0,15	0,04	0,19	-0,11	3	0,29877653	-51850	0	-3
		1977	197	596400	135973	732373	3123067	0,19	0,04	0,23	-0,07	4	0,22798994	69550	1	2
		Thessaloniki	-	345850	135973	481823	3123067	0,11	0,04	0,15	-0,15	3	0,39315657	-76150	-1	-2
Özzi Braces 4		Thessaloniki	Thessaloniki	408900	135973	544873	3123067	0,13	0,04	0,17	-0,13	3	0,33253412	-14150	0	-10
		1977	-		176765	176765	3123067	0,00	0,06	0,06	-0,24	0	-	-506950	-3	-0
		1977	197	586250	176765	763015	3123067	0,19	0,06	0,24	-0,06	3	0,3015184	59400	0	3
		Thessaloniki	-		176765	176765	3123067	0,00	0,06	0,06	-0,24	0	-	-422000	-2	-0
Özzi Braces 5		Thessaloniki	Thessaloniki	476700	176765	653465	3123067	0,15	0,06	0,21	-0,09	3	0,37081007	53650	0	3
Özzi	-	1990,1	-	333461	0	333461	2808021	0,12	0,00	0,12	-0,18	-	0			
Özzi	-	1990,2	-	389594	0	389594	2808021	0,14	0,00	0,14	-0,16	-	0			

Fig. 5. Efficiency of preventive retrofit versus postearthquake repair in case of alternatives of amount and placing of steel braces in reinforced concrete frames, simplified model

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