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AUTOMATED SELECTION OF VALUE EFFICIENT BUILDINGS REFURBISHMENT ALTERNATIVES

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ABSTRACT

It has often been assumed theoretically that refurbishment would enhance the market value of the aged buildings because it can restore and improve the building conditions physically and economically. However, refurbishment should be considered as investment which is not always profitable. In order to select value efficient refurbishment alternatives automated tools are used. The main purpose of this article is to propose automated system for value efficient refurbishment alternatives selection.

KEYWORDS

Refurbishment, Value Efficiency, Automated Selection of Alternatives, Investments

1. INTRODUCTION

The general dilemma of renovating vs. rebuilding has received only limited attention in the professional literature. It is indeed a multidisciplinary dilemma in which even the apparently numerical economic evaluation is not straightforward due to much uncertainty [1].

At present a benefit of buildings renovation was usually considered as only the saving of energy. It is obvious, however, that most energy saving measures allow not only to save energy, but also to improve the building's condition and in turn to increase the value of a building. According to Martinaitis et al. [1], building refurbishment projects, whose feasibility is assessed only with regards to energy efficiency, should be considered as the result of an "old attitude". It is unlikely that such projects meet the concepts of the six essential requirements for construction works as well as the need for sustainable development. Buildings, which form the accumulated wealth of a country during a long time and are frequently the largest asset of each country, should be refurbished, considering the benefit as well of the timely renewal of worn out building elements.

It is usually agreed that renovation would enhance the market value of the property, but there are few empirical studies on it. Theoretical models can be traced back to Sweeney [2], Dildine and Massey [3]. They developed models on the opposing impacts to the rate of depreciation of maintenance, on the premise that renovation produced net value enhancement. Arnott et al. [4] extended the model to include rehabilitation. More recent researches analyzed investment in renovation estimation problems. Mansfied [5] defined renovation as housing investment category, while Chau et al. [6] used hedonic model for multiple-ownership buildings refurbishment investment valuation.

Mao and Ruthenberg [7,8], argued that reconstruction should bear as "extra cost" the waste of demolishing a valuable though old and ill-functioning existing building, while the refurbishment option utilizes the existing value of the old building and just adds to it. In more recent papers decisions on economically efficient refurbishment are adapted to new technology methods: Adeli [9] applies general theories and techniques of expert systems to construction, Henket [10] suggests a theoretical model of several modular stages in the decision process, Reddy et al. [11] offer a frame-based decision support model for building renovation, Alanne [12] proposes a multi-criteria "knapsack" model to help designers select the most feasible renovation actions in the conceptual phase of a renovation project. Zavadskas, Kaklauskas, Raslanas et al. [13, 14] integrate various IT supported knowledge management, decision support, expert models for buildings' life cycle management as well as refurbishment projects' assessment and optimization.

In this paper The Building's Refurbishment Knowledge-based Decision Support System for automated value efficient buildings refurbishment alternatives selection is proposed.

2. VALUE EFFICIENT BUILDINGS REFURBISHMENT MEASURES IN VILNIUS

About 59% of apartments in dwelling houses in Vilnius are located in large-panel buildings. In brick and cast-in-place buildings they take 35% and 6% of all apartments in multifamily buildings, respectively. The types of buildings are not numerous. They include about seven varieties of large-panel houses, six types of brick and four types of cast-in-place buildings. Major problems associated with maintenance as well as defects and drawbacks found in panel houses are common to all such buildings constructed in the period from 1960 to 1996. Usually, the enclosure walls of these houses have poor thermal characteristics. In later structures, the requirements to these parameters are more rigorous. Therefore, considering these buildings from the economical point of view it may be stated that thermal insulation of some of their enclosures is by 4 – 4,5 times lower than specified by the regulations. This means that to make the above houses economical, thermal insulation of enclosures should be improved.

Another problem of the most of apartment buildings is not associated only with high thermal conductivity of their windows and doors, but is related with poor sealing caused by natural ageing and low quality of building products. As a result, in winter, cold air can easily infiltrate into the spaces and heat losses due to ventilation are also increased. Many problems arise in large-panel buildings (especially in the older ones) because of leaking joints between panels. Due to this, the walls are getting damp and even frozen (in cold weather).

The interior finishing of the apartments is damaged, thermal conductivity of walls and heat losses increase, worsening the microclimate of the spaces. The balconies in large-panel and in some brick houses are in a bad (sometimes, emergency) state. In brick houses, signs of wetting, crumbling and freezing of an external ceramic brick layer may be observed. In cast-in-place buildings some joints between floor slabs are not well sealed because the concrete was not properly compacted, thereby leaking water which sometimes penetrates the walls and gets into the wall cavity.

Roofs of apartment buildings are usually flat, covered with rolled material (e.g. ruberoid on the bituminous base) and having the internal water removal. Nearly all such roofs are characterized by heavy wearing of the covering and its bubbling. They also may leak water, especially near the parapets and water catchers. In brick houses, the walls often get damp if water leaks near the parapets.

All the above problems and defects indicate the need for innovation of Vilnius apartment buildings and of their surroundings. Therefore a demand for heating in these houses is two or more times higher than in those in Western countries [1].

Different scenarios of buildings refurbishment may be used. Four variants of renovation projects aimed to determine preliminary investments and their effectiveness have been prepared.

A set of refurbishment projects based on *small investments* is oriented to the replacement, reconstruction or repair of building elements which are in the worst technical conditions. This alternative is attractive because it is relatively cheap, but thermal characteristics of building enclosures are not improved much (except for doors and windows). The same applies to the architectural appearance and aesthetic characteristics of buildings.

A set of renovation projects based on *medium investments* is aimed at energy saving. It can provide rather high economic effect. The possibility to regulate temperature in the apartments and individually determine thermal energy consumption encourages the tenants to save energy. These savings may be relatively large. The alternative also provides for minimum outdoor amenities. However, the aesthetic view of a building is not considerably changed according to this renovation variant and the walls can hardly satisfy the currently used standards.

Projects based on *large investments* are aimed at providing the highest quality to a building, which would have the enclosures with thermal characteristics satisfying the standards, as well as possessing more advanced heating system allowing for accurate calculation of heat energy consumption and individual temperature regulation. From the economic point of view such houses are most effective, satisfying the standards specified for new construction. However, the investments are large (~300 Euro/m^2) being hardly affordable for an average-income family. This alternative is most suited for prestigious residential areas. Pitched roofs would allow arranging additional apartments which could be sold.

Accordingly to value efficiency refurbishment criteria, the priorities of Vilnius districts refurbishment were distinguished (see Figure 1).

After the refurbishment priorities selected, the second task is refurbishment alternatives selection. It is discussed further.

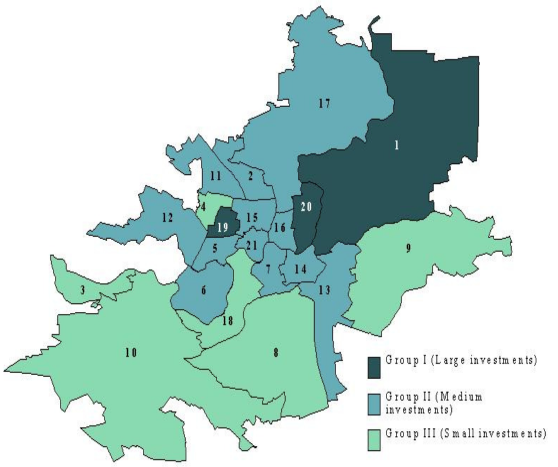


Figure 1. Map of refurbishment priorities in Vilnius

3. THE BUILDINGS REFURBISHMENT KNOWLEDGE BASED DECISION SUPPORT SYSTEM

In order to choose the best refurbishment alternative authors suggest using Complex Proportional Assessment method (COPRAS) [15, 16].

This method assumes direct and proportional dependence of significance and priority of investigated versions on a system of criteria adequately describing the alternatives and on values and significances of the criteria. The system of criteria is determined and the values and initial significances of criteria are calculated by experts. All this information can be corrected by interested parties (customer, users, etc.) taking into consideration their pursued goals and existing capabilities. Hence, the assessment results of alternatives fully reflect the initial refurbishment data jointly submitted by experts and interested parties.

The determination of significance and priority of alternatives is carried out in four stages.

Stage 1: The weighted normalized decision making matrix D is formed. The purpose of this stage is to receive dimensionless weighted values from the comparative indexes. When the dimensionless values of the indexes are known, all criteria, originally having different dimensions, can be compared. The following formula is used for this purpose:

$$d_{ij} = \frac{x_{ij} \cdot q_i}{\sum_{j=1}^{n} x_{ij}}, \quad i = \overline{1,m}; \quad j = \overline{1,n}. \tag{1}$$

where x_{ij} - the value of the i-th criterion in the j-th alternative of a solution; m - the number of criteria; n - the number of the alternatives compared; q_i - significance of i-th criterion.

The sum of dimensionless weighted index values d_{ij} of each criterion x_i is always equal to the significance q_i of this criterion:

$$q_i = \sum_{j=1}^{n} d_{ij}, \quad i = \overline{1,m}; j = \overline{1,n}. \tag{2}$$

In other words, the value of significance q_i of the investigated criterion is proportionally distributed among all alternative versions a_j according to their values x_{ij}.

Stage 2: The sums of weighted normalized indexes describing the j-th version are calculated. The versions are described by minimizing indexes S_{-j} and maximizing indexes S_{+j}. The lower value of minimizing indexes is better and the greater value of maximizing indexes is better. The sums are calculated according to the formula:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}; \quad S_{-j} = \sum_{i=1}^{m} d_{-ij}, \quad i = \overline{1,m}; j = \overline{1,n}. \tag{3}$$

In this case, the values S_{+j} (the greater is this value (project "pluses"), the more satisfied are the interested parties) and S_{-j} (the lower is this value (project "minuses"), the better is goal attainment by the interested parties) express the degree of goals attained by the interested parties in each alternative project. In any case the sums of "'pluses" S_{+j} and "minuses" S_{-j} of all alternative alternatives are always respectively equal to all sums of significances of maximizing and minimizing criteria:

$$S_{+} = \sum_{j=1}^{n} S_{+j} = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{+ij},$$
$$S_{-} = \sum_{j=1}^{n} S_{-j} = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{-ij}, \quad i = \overline{1,m}; j = \overline{1,n}. \tag{4}$$

Stage 3: The significance (efficiency) of comparative versions is determined on the basis of describing positive alternatives ("pluses") and negative alternatives ("minuses") characteristics. Relative significance Q_j of each alternative a_j is found according to the formula:

$$Q_j = S_{+j} + \frac{S_{-\min} \cdot \sum_{j=1}^{n} S_{-j}}{S_{-j} \cdot \sum_{j=1}^{n} \frac{S_{-\min}}{S_{-j}}}, \quad j = \overline{1,n}. \tag{5}$$

Stage 4: Priority determination of alternatives. The greater is the Q_j the higher is the efficiency (priority) of the refurbishment alternative.

The analysis of the method presented makes it possible to state that it may be easily applied to evaluating the projects and selecting most efficient of them, being fully aware of a physical meaning of the process. Moreover, it allowed formulating a reduced criterion Q_j which is directly proportional to the relative effect of the compared criteria values x_{ij} and significances q_i on the end result.

Significance Q_j of project a_j indicates satisfaction degree of demands and goals pursued by the interested parties - the greater is the Q_j the higher is the efficiency of the project.

The degree of project utility is directly associated with quantitative and conceptual information related to it. If one project is characterized by the best comfort ability, aesthetics, price indices, while the other shows better maintenance and facilities management characteristics, both having obtained the same significance values as a result of multiple criteria evaluation, this means that their utility degree is also the same. With the increase (decrease) of the significance of project analyzed, its degree of utility also increases (decreases). The degree of project utility is determined by comparing the project analyzed with the most efficient project. In this case, all the utility degree values related to the project analyzed will be ranged from 0% to 100%. This will facilitate visual assessment of project efficiency.

The formula used for the calculation of alternative a_j utility degree N_j is given below:

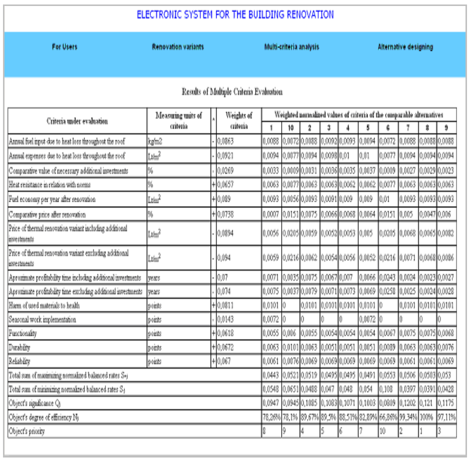
$$N_j = \left(Q_j : Q_{max}\right) \cdot 100\%. \qquad (6)$$

Basing on the COPRAS method, the Building's Refurbishment Knowledge-based Decision Support System (BR-DSS) was created. BR-DSS Decision Support Subsystem consists of a database, database management system, model-base, model-base management system and a user interface.

The BR-DSS allows users to: present information of the general physical and functional state of the building; present information of the physical state of the building's envelope; calculate the volume of work to be carried out; rationalize the energy consumption of the building; propose the required measures to increase the quality of air and indoor environment and analyze the refurbishment scenarios by taking into account the system of criteria.

A module base allows the BR-DSS's user to select the most suitable refurbishment alternatives by comparing the measures that promote the greatest value enhancement effects and increase a building's quality within the budget constraints of the building's inhabitants (see Figure 2).

The following models of a model-base aim at performing the functions of: a model for developing the alternative variants of a building's enclosures, a model for determining the initial weight of the criteria (with the use of expert methods), a model for the establishment of the criteria weight, a model for the multi-variant design of a building refurbishment, a model for multiple criteria analysis and for setting the priorities, a model for the determination of a project's utility degree and market value, a model for negotiations.



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Results of Multiple Criteria Evaluation

Criteria under evaluation	Measuring units of criteria	*	Weights of criteria	Weighted normalized values of criteria of the comparable alternatives									
				1	10	2	3	4	5	6	7	8	9
Annual fuel input due to heat loss throughout the roof	kg/m2	-	0,0863	0,0088	0,0072	0,0088	0,0092	0,0093	0,0094	0,0072	0,0088	0,0088	0,0088
Annual expenses due to heat loss throughout the roof	Lt/m^2	-	0,0921	0,0094	0,0077	0,0094	0,0098	0,01	0,01	0,0077	0,0094	0,0094	0,0094
Comparative value of necessary additional investments	%	-	0,0269	0,0033	0,0009	0,0031	0,0036	0,0035	0,0037	0,0009	0,0027	0,0029	0,0023
Heat resistance in relation with norms	%	+	0,0657	0,0063	0,0077	0,0063	0,0063	0,0062	0,0062	0,0077	0,0063	0,0063	0,0063
Fuel economy per year after renovation	Lt/m^2	+	0,089	0,0093	0,0056	0,0093	0,0091	0,009	0,009	0,01	0,0093	0,0093	0,0093
Comparative price after renovation	%	+	0,0738	0,0007	0,0151	0,0075	0,0066	0,0068	0,0064	0,0151	0,005	0,0047	0,006
Price of thermal renovation variant including additional investments	Lt/m^2	-	0,0894	0,0056	0,0205	0,0059	0,0052	0,0053	0,005	0,0205	0,0068	0,0065	0,0082
Price of thermal renovation variant excluding additional investments	Lt/m^2	-	0,094	0,0059	0,0216	0,0062	0,0054	0,0056	0,0052	0,0216	0,0071	0,0068	0,0086
Aproximate profitability time including additional investments	years	-	0,07	0,0071	0,0035	0,0075	0,0067	0,007	0,0066	0,0243	0,0024	0,0023	0,0027
Aproximate profitability time excluding additional investments	years	-	0,074	0,0075	0,0037	0,0079	0,0071	0,0073	0,0069	0,0258	0,0025	0,0024	0,0028
Harm of used materials to health	points	+	0,0811	0,0101	0	0,0101	0,0101	0,0101	0,0101	0	0,0101	0,0101	0,0101
Seasonal work implementation	points	-	0,0143	0,0072	0	0	0	0	0,0072	0	0	0	0
Functionality	points	+	0,0618	0,0055	0,006	0,0055	0,0054	0,0054	0,0054	0,0067	0,0075	0,0075	0,0068
Durability	points	+	0,0672	0,0063	0,0101	0,0063	0,0051	0,0051	0,0051	0,0089	0,0063	0,0063	0,0076
Reliability	points	+	0,067	0,0061	0,0076	0,0069	0,0069	0,0069	0,0069	0,0069	0,0061	0,0061	0,0069
Total sum of maximizing normalized balanced rates S_{+j}				0,0443	0,0521	0,0519	0,0495	0,0495	0,0491	0,0553	0,0506	0,0503	0,053
Total sum of minimizing normalized balanced rates S_{-j}				0,0548	0,0651	0,0488	0,047	0,048	0,054	0,108	0,0397	0,0391	0,0428
Object's significance Q_j				0,0947	0,0945	0,1085	0,1083	0,1071	0,1003	0,0809	0,1202	0,121	0,1175
Object's degree of efficiency N_j				78,26%	78,1%	89,67%	89,5%	88,51%	82,89%	66,86%	99,34%	100%	97,11%
Object's priority				8	9	4	5	6	7	10	2	1	3

Figure 2. Selection of roof refurbishment alternatives

Based on the above models, the BR-DSS can make up to 100,000 building refurbishment alternative versions, perform their multiple criteria analysis, determine the utility degree, market value and select the most beneficial alternative without human interference.

Basing oneself on the collected information and the BR-DSS it is possible to perform a multiple criteria analysis of the refurbishment project's components (walls, windows, roof, floors, volumetric planning and engineering services, etc.) and select the most efficient versions. After this, the received compatible and rational components of a refurbishment are joined into the projects. Having performed a multiple criteria analysis of the projects in this way, one can select the most energetically efficient projects [16].

4. CONCLUSIONS

The refurbishment scenarios should be chosen in such a way that the average market price of renovated dwellings and the cost of renovation project would not exceed the market value of a newly-built dwelling

Proposed Building's Refurbishment Knowledge-based Decision Support System (BR-DSS) can make up to 100,000 building refurbishment alternative versions, perform their multiple criteria analysis, determine the utility degree, market value and select the most beneficial alternative without human interference.

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