INFORMATICA, 2001, Vol. 12, No. 1, 169–188

Multivariant Design and Multiple Criteria Analysis of a Building Life Cycle

Edmundas Kazimieras ZAVADSKAS, Arturas KAKLAUSKAS,
Nerija KVEDERYTĖ
Department of Construction Technology and Management
Vilnius Gediminas Technical University
Sauletekio al. 11, 2040 Vilnius, Lithuania
e-mail: property@st.vtu.lt

Received: October 2000

Abstract. A lot of data had to be processed and evaluated in carrying out multivariant design and multiple criteria analysis of a building life cycle. The number of feasible alternatives can be as large as 100 000. Each of the alternatives may be described from various perspectives (economic, technical, qualitative, technological, social, legislative, infrastructural, etc.). The problem arises how to perform multivariant design and multiple criteria analysis of the alternative variants based on this enormous amount of information. To solve this problem the methods of multivariant design and multiple criteria building life cycle analysis were developed. In order to demonstrate the theory an example is given in this paper.

Key words: new methods, building life cycle, multivariant design, multiple criteria analysis.

1. Introduction

A building life cycle consists of four closely interrelated stages: brief, design, construction and maintenance. A building life cycle may have a lot of alternative versions. These variants are based on the alternative brief, design, construction, maintenance and facilities management processes and their constituent parts. The above solutions and processes may be further considered in more detail. For instance, the alternative building variants may be developed by varying its three-dimensional planning, as well as structural and engineering solutions. Thus, dozens of thousands of building life cycle alternative versions can be obtained. The diversity of solutions available contributes to more accurate evaluation of climatic conditions, risk exposure, maintenance services, as well as making the project cheaper and better satisfying a client's architectural, comfortability, technological and other requirements. This also leads to better satisfaction of the needs of all parties involved in the project design and realization.

Various interested parties (clients, users, architects, designers, utilities engineers, economists, contractors, maintenance engineers, suppliers, finansing institutions, local government, state and state institutions) are involved in the life cycle of a building, trying to satisfy their needs and affecting its efficiency. The above needs or objectives embrace the expected cost of a building, maintenance costs, living space, number of floors as well as the requirements to its architecture, aesthetics, comfortability, functionality, proportions, materials, sound insulation of partition walls, taxes and allowances, interest rates, etc. Besides, the environment of the site, its ecology, sound level and local infrastructure are also taken into consideration. This list may be continued.

The level of the efficiency of life cycle of a building depends on a number of variables, at two levels: micro and macro level. The efficiency of the life cycle of a building depends on the influence of many complex macro level factors (policy executed by the government, legal and institutional infrastructure, physical infrastructure, financial sector, environment issues, unemployment, interest rate, inflation, innovations, exchange rate). The efficiency level will, therefore, vary depending on the aggregate effect of these macro level factors.

The efficiency level of the life cycle of a building also depends on various micro level factors (sources of company finance, information system of construction, types of contracts, construction employers associations, education and training, brief, designing, manufacture, construction and maintenance processes, etc.) some of which depend on the influence of the macro level factors. For instance, the system of taxation which is set at the macro level (following fiscal policy of the government), exerts a direct influence on wages and salaries (and thereby disposable incomes) and on prices of materials at the micro level (project level). The standpoint of the State (various laws and decrees, working of State institutions, etc.) regarding certain activities exert considerable influence on the efficiency of organizations. The relations of various interested parties (for instance, between customer and contractor) are directly governed by law.

The problem is how to define an efficient building life cycle when a lot of various parties are involved, the alternative project versions come to hundreds thousand and the efficiency changes with the alterations in the environment conditions and the constituent parts of the process in question. Moreover, the realization of some objectives seems more rational from the economic perspective thought from the other perspectives they have various importance. Therefore, it is considered that the efficiency of a building life cycle depends on the rationality of its stages as well as on the ability to satisfy the needs of the interested parties and the rational character of environment conditions.

2. A Survey of Research Problems Investigated in the Field of a Building Life Cycle

Research into a building life cycle aimed to increase its efficiency being done in the world may be classified in various ways:

- the investigations aimed at solving actual problems of a particular stage of a building life cycle (i.e., brief, design, construction, maintenance, facilities management);
- the investigations handling a certain problem through the whole life cycle of a building;
- the investigations aimed to increase overall efficiency of a life cycle of a building;

- the investigations aimed to increase the efficiency of a life cycle of a building or its particular stage by applying recent achievements of IT and the Internet.

Kalay *et al.* (1998) developed an integrated design system enabling designers to work out a number of project versions as well as evaluating them. Dupagne and Mathus (1998) created CABMAS, an integrated construction system for one-family houses allowing multivariant design of one-family house with a possibility to simulate a number of construction variants during the process of actual construction. This system takes into account not only the requirements of the client and his financial position, but also considers the construction of other objects carried out by the company.

Goicoechea *et al.* (1987) analyzed the following multiple criteria decision making methods: utility function assessment (Keeney); compromise programming (Zeleny); Electre (Roy, Duckstein); surrogate worth trade-off (Haimes); multiobjective Simplex (Yu, Zeleny); method by Zionts, Wallenius; Ariadne (Sage, White); probabilistic trade-off development, Protrade (Goicoechea, Duckstein); goal programming (Lee, Ignizio).

Ozernoy (1987; 1992) presented a number of multiple criteria decision making methods to be used in solving discrete alternative problems: weighting methods (MacCrimon), multiattribute utility theory (Keeney and Raiffa), measurable value theory (Dyer and Sarin), analytical hierarchical method (Saaty), weighted-additive evaluation function with partial information (Kirkwood and Sarin), multiattribute method with incomplete information (Weber), pairwise comparison of alternatives with ordinal criteria (Koksalan, Karwan and Zionts), simple multiattribute utility method (Einhorn and McCoach), Electre I, II and III (Roy and Vincke).

The above research was mainly dealing with the problems of multivariant design relating to particular stages of a building life cycle. Multivariant design methods to be applied to the whole building life cycle were suggested by Dupagne and Mathus (1998), but they were not completely computer-aided. In order to solve the problems raised in the present investigation the attempt was made to carry out computer-aided multiple criteria multivariant design of a building life cycle. This is briefly described below.

3. Gathering of Initial Data for Multiple Criteria Analysis

The determination of the utility degree and value of the building life cycle under investigation and establishment of the priority order for its implementation does not present much difficulty if the criteria numerical values and importance have been obtained and the multiple criteria decision making methods are used.

All criteria are calculated for the whole project. The process of determining the system of criteria, their initial importance and qualitative criteria numerical values of the project under investigation are based on the use of various expert methods. The determination of quantitative criteria numerical values is based on the use of various statistical methods, analysed projects, recommendations, price-lists, reference books, building codes, specifications and other documents.

The magnitude of importance indicates how many times one criterion is more/less important than the other one in a multiple criteria evaluation of projects.

The results of the comparative analysis of the projects are presented as a grouped decision making matrix where columns contain *n* alternative projects being considered, while all quantitative and conceptual information pertaining to them is found in lines.

Quantitative and conceptual description provides the information about various aspects of a building life cycle (i.e., economical, legislative, technical, technological, infrastructural, qualitative (architectural, aesthetic, comfortability), social ones, etc.).

Conceptual description of a building life cycle presents textual, graphical (schemes, graphs, diagrams, drawings), visual (videotapes) information about the projects and the criteria used for their definition, as well as giving the reason for the choice of this particular system of criteria, their values and importance. This part also includes information about the possible ways of multivariant design. Conceptual information is needed to make more complete and accurate evaluation of the alternatives considered. It also helps to get more useful information as well as developing a system and subsystems of criteria and defining their values and importance.

Quantitative information is based on the criteria systems and subsystems, units of measure, values and initial importance as well as the data on the alternative projects development.

The grouping of the information in the matrix should be performed so as to facilitate the calculation process and to express their meaning. In our case the criteria system are formed from the criteria describing the life cycle of a building which can be expressed in a quantitative form (quantitative criteria) and the criteria describing the life cycle of a building which cannot be expressed in a quantitative form (qualitative criteria).

Table 1

Grouped decision making matrix of building life cycle multiple criteria analysis

Quantitative information pertinent to projects										
Criteria describing the life cycle of a building		*	Importance	Measuring units	Compared projects					
					1	2	...	j	...	n
Quantitative criteria	X_1	z_1	q_1	m_1	x_{11}	x_{12}	...	x_{1j}	...	x_{1n}
	X_2	z_2	q_2	m_2	x_{21}	x_{22}	...	x_{2j}	...	x_{2n}
	...	...	...	...	...	...	...	...	...	...
	X_i	z_i	q_i	m_i	x_{i1}	x_{i2}	...	x_{ij}	...	x_{in}
	...	...	...	...	...	...	...	...	...	...
	X_t	z_t	q_t	m_t	x_{t1}	x_{t2}	...	x_{tj}	...	x_{tn}
Qualitative criteria	X_{t+1}	z_{t+1}	q_{t+1}	m_{t+1}	$x_{t+1\,1}$	$x_{t+1\,2}$	...	$x_{t+1\,j}$	...	$x_{t+1\,n}$
	X_{t+2}	z_{t+2}	q_{t+2}	m_{t+2}	$x_{t+2\,1}$	$x_{t+2\,2}$	...	$x_{t+2\,j}$	...	$x_{t+2\,n}$
	...	...	...	...	...	...	...	...	...	...
	X_i	z_i	q_i	m_i	x_{i1}	x_{i2}	...	x_{ij}	...	x_{in}
	...	...	...	...	...	...	...	...	...	...
	X_m	z_m	q_m	m_m	x_{m1}	x_{m2}	...	x_{mj}	...	x_{mn}
Conceptual information pertinent to projects (i.e. text, drawings, graphics, video tapes)										
C_f		C_z	C_q	C_m	C_1	C_2	...	C_j	...	C_n

* The sign z_i (+ (−)) indicates that a greater (less) criterion value corresponds to a higher importance for a client.

4. The Determination of Criteria Importance

In order to select the best building life cycle, it is necessary, having formed the grouped decision making matrix to perform the multiple criteria analysis of the projects. This is done by comparing criteria numerical values and importance and analyzing the conceptual information of the investigated project. The life cycle of an investigated project can be described only on the basis of a criteria system comprising many criteria with different meanings and dimensions. Such variety of criteria makes it difficult to compare the projects directly. One of the major tasks in solving the above problem is to determine the importance of the criteria. It is most commonly done by means of expert methods.

Theoretical and practical aspects of expert methods in construction were dealt with in various research papers by Arditi *et al.* (1989; 1998), Bana E Costa *et al.* (1997; 1998), Chinyio *et al.* (1998) and others. Having determined the importance of criteria by expert methods, we learn how much one of the criteria is more important than another one. However, having determined by these methods the importance of quantitative criteria (cost of plot and building, maintenance costs, construction time, etc.), we do not find out everything we need. With the change of values of quantitative criteria, their importance is changing as well. Further on follows the description of a new method (developed by the authors) of complex determination of the importance of the criteria taking into account their quantitative and qualitative characteristics.

Importance of criteria may be calculated applying some methods. Application of the method submitted in next sub-chapter is efficient in case of the alternatives are under evaluation basing on some quantitative criteria. In case of the system of criteria includes one quantitative criterion, it is more simple to apply expert methods for definition of importance of criteria.

When performing multiple criteria assessment of projects it is necessary to normalize the values of criteria describing the projects and then to weight them. This creates a possibility to compare the values of criteria with different measuring units and to determine the most efficient alternatives. The weighting of criteria is performed by the multiplication of their normalized values and their importance. Therefore, the importance of all criteria must be coordinated among themselves, taking into consideration their quantitative and qualitative characteristics. The importance of quantitative criteria can be exactly coordinated among themselves if the values of quantitative criteria are expressed through an equivalent monetary unit (Stages 1–4). Having performed strict mutual coordination of quantitative criteria importance, the same is done with the importance of qualitative criteria (Stages 5–7). In this case the importance of qualitative and quantitative criteria is coordinated exactly at the same time.

Having determined the system of criteria describing the alternatives and calculated numerical values and initial importance of criteria and having presented them in the form of grouped decision making matrix, the user should calculate the actual importance of criteria. The values of criteria must be calculated for the whole project. The calculation of the criteria importance is carried out in seven stages. In the Stages 1–4 the importance of quantitative criteria is identified whereas in the Stages 5–7 the importance of qualitative criteria is identified.

Stage 1. The determination of the sum of values for every quantitative criterion:

$$S_i = \sum_{j=1}^{n} x_{ij}, \quad i = \overline{1,t}; \quad j = \overline{1,n}, \tag{1}$$

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

Stage 2. The total monetary expression of every quantitative criterion describing the investigated project is obtained by:

$$P_i = S_i \cdot p_i, \quad i = \overline{1,t}, \tag{2}$$

where p_i – initial importance of the i criteria. p_i should be measured in such a way as, being multiplied by a quantitative criterion value, an equivalent monetary expression could be obtained.

According to their effect on the efficiency of the project in time the quantitative criteria may be divided into:

- short-term factors affecting the project for a certain period of time only;
- long-term factors affecting the project throughout its life cycle.

The initial importance of long-term criteria, like resources needed for the maintenance, environment protection, etc. is dependent on the repayment time of the projects as well as on the evaluation in money terms of a measure unit of a criterion:

$$p_i = e \cdot f_i, \tag{3}$$

where e – repayment time of a project; f_i – monetary evaluation of a measure unit of the i criterion.

The initial importance of a single criteria comprising evaluation of duration of construction, the cost of plot, etc. equals the measure unit of a criterion in money terms:

$$p_i = f_i. \tag{4}$$

Stage 3. The overall quantitative criteria magnitude sum expressed in money terms is determined:

$$V = \sum_{i=1}^{t} P_i, \quad i = \overline{1,t}. \tag{5}$$

Stage 4. The quantitative criteria importance describing the project, which can be expressed in money terms, is determined as follows:

$$q_i = \frac{P_i}{V}, \quad i = \overline{1,t}. \tag{6}$$

If the above method is applied in calculation of importance, the total sum of importance quantitative criteria is always equal to 1:

$$\sum_{i=1}^{t} q_i = 1. \tag{7}$$

The qualitative criteria importance pertaining to the life cycle of a building is determined in Stages 5–7.

Stage 5. In order to achieve full coordination between the importance of quantitative and qualitative criteria, a compared standard value (E) is set. It is equal to the sum of any selected importance of quantitative criteria. One of the main requirements for this compared standard value is that according to utility it should be easily comparable with all qualitative criteria. In this case, the importance of all qualitative criteria are determined by the comparison of their utility with the importance of the compared standard value. E is determined according to the following formula:

$$E = \sum_{z=1}^{g} q_z, \tag{8}$$

where g is the number of quantitative criteria included into the compared standard; q_z is the importance of z quantitative criterion included into the compared standard.

Stage 6. The initial importance v_i of qualitative criteria is determined by expert methods comparing their relative importance to the importance E of the selected compared standard. In this case, relative importance of qualitative criteria should be expressed in per cent.

Stage 7. The importance of qualitative criteria is determined as follows:

$$q_i = \frac{\nu_i \cdot E}{100}, \quad i = t+1, \ldots, m. \tag{9}$$

The above method allows to determine importance of criteria which is maximally interrelated and depend on qualitative and quantitative characteristics of all criteria.

5. A Method of Multiple Criteria Complex Proportional Evaluation of a Building Life Cycle

The method of complex proportional evaluation assumes direct and proportional dependence of importance and priority of investigated versions on a system of criteria adequately describing the alternatives and on values and importance of the criteria. The system of criteria is determined and the values and initial importance 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 data jointly submitted by experts and interested parties.

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

Stage 1. The weighted normalized decision making matrix D is formed (see Table 2). 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:

$$d_{ij} = \frac{x_{ij} \cdot q_i}{\sum_{j=1}^{n} x_{ij}}, \quad i = \overline{1,m}; \quad j = \overline{1,n}, \tag{10}$$

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 – importance of i-th criterion.

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

$$q_i = \sum_{j=1}^{n} d_{ij}, \quad i = \overline{1,m}; \quad j = \overline{1,n}. \tag{11}$$

In other words, the value of importance 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 (price of the plot and building, etc.). The greater value of maximizing indexes is better (comfortability and aesthetics of

Table 2 Building life cycle multiple criteria analysis results

Criteria under evaluation	Measuring units	*	Importance	Compared projects (matrix D)					
				1	2	...	j	...	n
X_1	m_1	z_1	q_1	d_{11}	d_{12}	...	d_{1j}	...	d_{1n}
X_2	m_2	z_2	q_2	d_{21}	d_{22}	...	d_{2j}	...	d_{2n}
...	...	...	...	...	...	...	...	...	...
X_i	m_i	z_i	q_i	d_{i1}	d_{i2}	...	d_{ij}	...	d_{in}
...	...	...	...	...	...	...	...	...	...
X_m	m_m	z_m	q_m	d_{m1}	d_{m2}	...	d_{mj}	...	d_{mn}
The sums of weighted normalized maximizing indices of the project				S_{+1}	S_{+2}	...	S_{+j}	...	S_{+n}
The sums of weighted normalized minimizing indices of the project				S_{-1}	S_{-2}	...	S_{-j}	...	S_{-n}
Importance of the project				Q_1	Q_2	...	Q_j	...	Q_n
Priority of the project				Pr_1	Pr_2	...	Pr_j	...	Pr_n
Utility degree of the project (%)				N_1	N_2	...	N_j	...	N_n

* The sign z_i (+ (–)) indicates that a greater (less) criterion value corresponds to a higher importance for a client.

the building, etc.). The sums are calculated according to the formula:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}; \quad S_{-j} = \sum_{i=1}^{m} d_{-ij}, \quad i = \overline{1,m}; \; j = \overline{1,n}. \tag{12}$$

In this case, the values S_{+j} (the greater is this value, the more satisfied are the interested parties) and S_{-j} (the lower is this value, 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 projects are always respectively equal to all sums of importance of maximizing and minimizing criteria:

$$S_{+} = \sum_{j=1}^{n} S_{+j} = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{+ij}, \quad S_{-} = \sum_{j=1}^{n} S_{-j} = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{-ij}, \tag{13}$$
$$i = \overline{1,m}; \; j = \overline{1,n}.$$

In this way, the calculations made may be additionally checked.

Stage 3. The importance (efficiency) of comparative versions is determined on the basis of describing positive projects S_{+j} and negative projects S_{-j} characteristics. Relative importance Q_j of each project a_j is found according to the formula:

$$Q_j = S_{+j} + \frac{S_{-\min} \cdot \sum_{j=1}^{n} S_{-j}}{S_{-j} \cdot \sum_{j=1}^{n} \frac{S_{-\min}}{S_{-j}}}, \quad j = \overline{1,n}. \tag{14}$$

Stage 4. Priority determination of projects. The greater is the Q_j the higher is the efficiency (priority) of the project.

Importance 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. In this case, the importance $Q_{\max}$ of the most rational project will always be the highest. The importance of all remaining projects is lower as compared with the most rational one. This means that total demands and goals of interested parties will be satisfied to a smaller extent than it would be in case of the best 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 comfortability, aesthetics, price indices, while the other shows better maintenance and facilities management characteristics, both having obtained the same importance values as a result of multiple criteria evaluation, this means that their utility degree is also the same. With the increase (decrease) of the importance of a project analyzed, its degree of utility also increases (decreases). The degree of project utility is determined by comparing the project analysed 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.

Stage 5. The formula used for the calculation of project a_j utility degree N_j is given below:

$$N_j = (Q_j : Q_{\max}) \cdot 100\%. \tag{15}$$

6. Multivariant Design of a Building Life Cycle

A lot of data had to be processed and evaluated in carrying out multivariant design of a building life cycle. The number of feasible alternatives can be as large as 100 000. Each of the alternatives may be described from various perspectives, e.g., by conceptual and quantitative information. The problem arises how to perform computer-aided design of the alternative variants based on this enormous amount of information. To solve this problem a new method of multiple criteria multivariant building life cycle design was developed. According to the above method multiple criteria multivariant design is carried out in 5 stages (Fig. 1) which are briefly described below.

Let us consider these stages.

In order to reduce the amount of information being used in computer-aided multivariant design the codes of the alternative solutions are used. In this case, any i solution of j alternative is given a_{ij} code providing thorough quantitative (system of criteria, units of measure, importance, values, as well as a minimizing or maximizing criterion) and conceptual (text, drawings, graphics, video tapes) information about the alternative being considered (see Table 3). Thus, the use of codes of the alternative solutions in computer-aided multivariant design reduces the volume of information to be processed providing better insight into a meaning of computations.

Codes, with conceptual and quantitative information provided, are used for describing all available alternative project solutions. The total number of these codes makes the table of codes of building life cycle alternatives allowing to get the alternative versions in a more simple way. As can be seen from Table 3, it contains c solutions of a building life cycle (plots, buildings, contractors, maintenance process, etc.) of the n_i alternative versions codes.

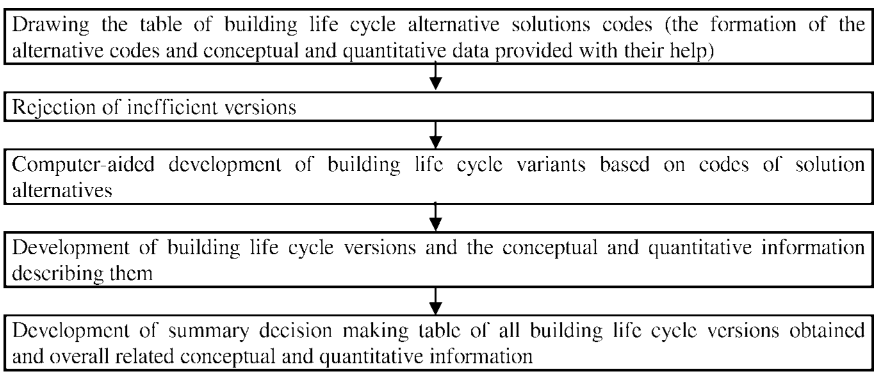

Fig. 1. Main stages of multiple criteria multivariant design of a building life cycle.

Table 3

Codes of building life cycle alternative solutions with conceptual and quantitative information

Solutions considered	The codes of the alternative solutions considered						
	1	2	3	...	j	...	n_i
1. Plot variants	a_{11}	a_{12}	a_{13}	...	a_{1j}	...	$a_{1\,n1}$
2. Building variants	a_{21}	a_{22}	a_{23}	...	a_{2j}	...	$a_{2\,n2}$
...	...	...	...	...	...	...	...
i. Well-being variants	a_{i1}	a_{i2}	a_{i3}	...	$\boldsymbol{a_{ij}}$	...	$a_{i\,ni}$
...	...	...	...	...	...	...	...
c. Maintenance variants	a_{c1}	a_{c2}	a_{c3}	...	a_{cj}	...	$a_{c\,nc}$

The information provided by code a_{ij} of i solution j alternative

Conceptual information	Quantitative information						
	Cost, X_1	Aesthetics, X_2	Comfortabi-lity, X_3	...	X_j	...	Quality, X_n
C_{ij}	$x_{ij\,1}$	$x_{ij\,2}$	$x_{ij\,3}$	...	$x_{ij\,j}$	...	$x_{ij\,n}$
Units of measure	Lt	Points	Points	...	...	...	Points
Importance	$q_{ij\,1}$	$q_{ij\,2}$	$q_{ij\,3}$	...	$q_{ij\,j}$	...	$q_{ij\,n}$
*	$z_{ij\,1}$	$z_{ij\,2}$	$z_{ij\,3}$	...	$z_{ij\,j}$	...	$z_{ij\,n}$

* Signs z_{ij} (+ (−)) mean, that corresponding higher (lower) value of the criterion better satisfies the client's needs

Any i line of the code table represents the codes of A_i solution a_{ij} alternatives. If the information relating to the solutions in the code table of building life cycle alternatives is represented by codes, then the code contains quantitative and conceptual information (see Table 3). In this case, n_i alternatives of any i solution are being considered in developing the alternative versions of a building life cycle. Thus, the maximum number of the projects obtained may be computed as follows:

$$k = \prod_{i=1}^{c} n_i, \tag{16}$$

where c is the number of solutions considered in determining a building life cycle; n_i – is the number of i solution alternatives to be used in developing a building life cycle.

For example, if in determining possible building life cycle alternative versions 10 alternatives are considered for any of 10 solutions, then, according to equation 16 maximum ten billion such variants will be obtained. It is evident that in this and similar cases it is hardly possible and reasonable to analyze all the versions from various perspectives. Therefore, it is advisable to reduce their number as follows. If a project of c solutions having n_i alternatives allows k combinations (Eq. 16) then, by using multiple criteria analysis methods, p most efficient versions should be chosen from every solution for further consideration (see Table 4). In this way, inefficient variants are being removed. The best solutions alternatives obtained are then grouped according to priority considerations. In Table 4 a_{i1} is a code of the best variant of i solution, while a_{ip} is a code of its worst version.

Table 4 Most efficient solution alternatives set according their priorities

Solutions considered	Priority of the best alternative solutions						
	1	2	3	...	j	...	p
1. Plot variants	a_{11}	a_{12}	a_{13}	...	a_{1j}	...	a_{1p}
2. Building variants	a_{21}	a_{22}	a_{23}	...	a_{2j}	...	a_{2p}
...	...	...	...	...	...	...	...
i. Well-being variants	a_{i1}	a_{i2}	a_{i3}	...	a_{ij}	...	a_{ip}
...	...	...	...	...	...	...	...
c. Maintenance variants	a_{c1}	a_{c2}	a_{c3}	...	a_{cj}	...	a_{cp}

Table 5 Computer-aided development of building life cycle variants based on codes of solution alternatives

Solutions considered	Development of building life cycle variants based on codes of solution alternatives											
	1	2	3	...	p	p+1	p+2	p+3	...	2p	...	K
1. Plot variants	a_{11}	a_{11}	a_{11}	...	a_{11}	a_{11}	a_{11}	a_{11}	...	a_{11}	...	a_{1p}
2. Building variants	a_{21}	a_{21}	a_{21}	...	a_{21}	a_{21}	a_{21}	a_{21}	...	a_{21}	...	a_{2p}
...	...	...	...	...	...	...	...	...	...	...	...	...
i. Well-being variants	a_{i1}	a_{i1}	a_{i1}	...	a_{i1}	a_{i1}	a_{i1}	a_{i1}	...	a_{i1}	...	a_{ip}
...	...	...	...	...	...	...	...	...	...	...	...	...
c-1. ...	$a_{c-1\,1}$	$a_{c-1\,1}$	$a_{c-1\,1}$	...	$a_{c-1\,1}$	$a_{c-1\,2}$	$a_{c-1\,2}$	$a_{c-1\,2}$	...	$a_{c-1\,2}$	...	$a_{c-1\,p}$
c. Maintenance variants	a_{c1}	a_{c2}	a_{c3}	...	a_{cp}	a_{c1}	a_{c2}	a_{c3}	...	a_{cp}	...	a_{cp}

Then, project variants are being developed based on the efficient p alternatives of c solutions chosen. At the beginning, this process should involve the codes of the alternative solutions. The first building life cycle variant is obtained by analyzing the best solution variants according to the priority order (see Table 4 and Table 5). The last variant is based on solution versions from the bottom of priority table, while intermediate variants are obtained with account of the versions found in the middle of this table. For example, the first building life cycle version is based on a_{11} plot, a_{21} building, a_{i1} well-being, a_{c1} maintenance, etc. variants. The last building life cycle version takes into account a_{1p} plot, a_{2p} building, a_{ip} well-being, a_{cp} maintenance, etc. variants. In this case, combinations are obtained by using p alternatives from any c solutions. Therefore, the maximum number of the projects obtained may be determined from the following expression:

$$K = \prod_{i=1}^{c} p, \tag{17}$$

where c is the number of solutions used in determining a building life cycle; p is the number of the best variants of every solution used in developing a building life cycle.

While in Table 5 the development of building life cycle alternatives was based on codes of solution alternatives, Table 6 presents conceptual and quantitative information about the variants instead of the codes. When a particular building life cycle is being considered the values relating to various solutions but based on the same criterion are recalculated into a single reduced value.

The reduction of the same criterion (e.g., cost, comfortability) values of various solutions (plot, building, well-being, maintenance) to a single one is necessary to appraise importance of these solutions. For example, noise level within and outside the building is not of the same importance to its inhabitants. The same applies to paying the money

Table 6

Development of building life cycle variants and related conceptual and quantitative information

Solutions used in developing building life cycle variants	Information related to building life cycle versions							
	Conceptual	Quantitative						
		Cost, X_1 (Lt)	Aesthetics, X_2 (Points)	Comfortability, X_3 (Points)	...	X_j	...	Quality, X_n (Points)
	Information related to life cycle of 1-st building							
1. Plot, a_{11}	C_{11}	$x_{11\,1}$	$x_{11\,2}$	$x_{11\,3}$	...	$x_{11\,j}$	...	$x_{11\,n}$
2. Building, a_{21}	C_{21}	$x_{21\,1}$	$x_{21\,2}$	$x_{21\,3}$	...	$x_{21\,j}$	...	$x_{21\,n}$
...		...	...	...	...	...	...	...
i. Well-being, a_{i1}	C_{i1}	$x_{i1\,1}$	$x_{i1\,2}$	$x_{i1\,3}$	...	$x_{i1\,j}$	...	$x_{i1\,n}$
...		...	...	...	...	...	...	...
c. Maintenance, a_{c1}	C_{c1}	$x_{c1\,1}$	$x_{c1\,2}$	$x_{c1\,3}$	...	$x_{c1\,j}$	...	$x_{c1\,n}$
	Information related to life cycle of 2-nd building							
1. Plot, a_{11}	C_{11}	$x_{11\,1}$	$x_{11\,2}$	$x_{11\,3}$	...	$x_{11\,j}$	...	$x_{11\,n}$
2. Building, a_{21}	C_{21}	$x_{21\,1}$	$x_{21\,2}$	$x_{21\,3}$	...	$x_{21\,j}$	...	$x_{21\,n}$
...		...	...	...	...	...	...	...
i. Well-being, a_{i1}	C_{i1}	$x_{i1\,1}$	$x_{i1\,2}$	$x_{i1\,3}$	...	$x_{i1\,j}$	...	$x_{i1\,n}$
...		...	...	...	...	...	...	...
c. Maintenance, a_{c2}	C_{c2}	$x_{c2\,1}$	$x_{c2\,2}$	$x_{c2\,3}$	...	$x_{c2\,j}$	...	$x_{c2\,n}$
...	...	...	...	...	...	...	...	...
	Information related to life cycle of *p*-th building							
1. Plot, a_{11}	C_{11}	$x_{11\,1}$	$x_{11\,2}$	$x_{11\,3}$	...	$x_{11\,j}$	...	$x_{11\,n}$
2. Building, a_{21}	C_{21}	$x_{21\,1}$	$x_{21\,2}$	$x_{21\,3}$	...	$x_{21\,j}$	...	$x_{21\,n}$
...		...	...	...	...	...	...	...
i. Well-being, a_{i1}	C_{i1}	$x_{i1\,1}$	$x_{i1\,2}$	$x_{i1\,3}$	...	$x_{i1\,j}$	...	$x_{i1\,n}$
...		...	...	...	...	...	...	...
c. Maintenance, a_{cp}	C_{cp}	$x_{cp\,1}$	$x_{cp\,2}$	$x_{cp\,3}$	...	$x_{cp\,j}$	...	$x_{cp\,n}$
...	...	...	...	...	...	...	...	...
	Information related to life cycle of the last (*K*) building							
1. Plot, a_{1p}	C_{1p}	$x_{1p\,1}$	$x_{1p\,2}$	$x_{1p\,3}$	...	$x_{1p\,j}$	...	$x_{1p\,n}$
2. Building, a_{2p}	C_{2p}	$x_{2p\,1}$	$x_{2p\,2}$	$x_{2p\,3}$	...	$x_{2p\,j}$	...	$x_{2p\,n}$
...		...	...	...	...	...	...	...
i. Well-being, a_{ip}	C_{ip}	$x_{ip\,1}$	$x_{ip\,2}$	$x_{ip\,3}$	...	$x_{ip\,j}$	...	$x_{ip\,n}$
...		...	...	...	...	...	...	...
c. Maintenance, a_{cp}	C_{cp}	$x_{cp\,1}$	$x_{cp\,2}$	$x_{cp\,3}$	...	$x_{cp\,j}$	...	$x_{cp\,n}$

(it depends on whether – this should be done at the present moment or in some years). The above importance of the solutions is determined by using expert, financial analysis and other methods. The importance should be made compatible in two directions: horizontally (among criteria) and vertically (among solutions). In this way, Table 6 may be transformed into a summary decision making table (see Table 7) containing all building life cycle versions and overall related information.

7. Practical Example

A young four-person family wishes to build an efficient single-family dwelling in a convenient for living place. In order to implement this objective it is necessary to make analysis of alternative variants of plots of land, single-family dwellings, contractors and dwellings maintenance. Taking into consideration wishes and possibilities of the family 5 variants of plots of land (see Table 8), 5 variants of single-family dwellings (see Table 9), 3 variants of contractors, and 5 possible variants of dwellings maintenance have been analysed.

Table 7

Summary decision making table of all building life cycle versions obtained and overall related conceptual and quantitative information

Building life cycle (BLC) versions obtained	Information related to building life cycle versions								
	Concep-tual	Quantitative							
		Cost, X_1	Aesthetics, X_2	Comfor-tability, X_3	...	X_j	...	Quality, X_n
1 BLC version	C_1	x_{11}	x_{12}	x_{13}	...	x_{1j}	...	x_{1n}
2 BLC version	C_2	x_{21}	x_{22}	x_{23}	...	x_{2j}	...	x_{2n}
3 BLC version	C_3	x_{31}	x_{32}	x_{33}	...	x_{3j}	...	x_{3n}
...		...	...	...	...	...	...	...
i BLC version	C_i	x_{i1}	x_{i2}	x_{i3}	...	x_{ij}	...	x_{in}
...		...	...	...	...	...	...	...
K BLC version	C_K	x_{K1}	x_{K2}	x_{K3}	...	x_{Kj}	...	x_{Kn}
Importance of criteria		q_1	q_2	q_3	...	q_j	...	q_n
Measuring units of criteria		Lt	Points	Points	...	...	...	Points

Table 8

Initial data for plots multiple criteria analysis

Criteria under evaluation	Measu-ring units of criteria	*	Importan-ce of criteria	Numerical values of criteria of the compared variants				
				1	2	3	4	5
1. Price of a plot of land	Lt/m^2	–	0,4369	120	80	40	46	29
2. Engineering networks (electric power, water supply, sewerage, heat, gas supply networks)	Points	+	0,2153	10,00	10,00	10,00	10,00	3,00
3. Telephone	Points	+	0,0297	10,00	10,00	10,00	10,00	10,00
4. Recreational opportunities	Points	+	0,0256	7,40	1,20	10,00	10,00	2,07
5. Roads and access opportunities	Points	+	0,0315	10,00	8,27	3,60	3,60	2,73
6. Dwelling territory	Points	+	0,0289	9,13	9,60	7,07	7,07	3,60
7. Neighbours	Points	+	0,0230	9,33	9,60	7,47	7,60	4,80
8. District prestige	Points	+	0,0259	9,53	9,27	7,40	7,40	1,00
9. Opportunities of development of a district	Points	+	0,0177	9,60	8,67	4,07	4,07	1,00
10. Volume of a plot of land	Points	+	0,0378	8,40	9,40	6,80	6,80	9,20
11. Configuration of a plot of land	Points	+	0,0340	9,47	9,73	7,47	5,67	8,00
12. Position of a plot of land in respect of other plots	Points	+	0,0469	10,00	8,47	5,87	8,53	8,53
13. Properties of ground	Points	+	0,0253	10,00	10,00	9,00	9,00	10,00
14. Air pollution	Points	–	0,0215	1,00	0,00	0,00	0,00	0,00

Following the technique described above values and importance of various alternative building life cycle solutions (plots of land, single-family dwellings, contractors, dwellings maintenance) should be determined in the first place. The values and importance obtained will be analysed using the example of single-family dwellings.

The efficiency level of the considered single-family dwellings depends on a great many factors, including: estimated cost, annual expenditure of comparative fuel for heating a building, physical longevity, comfort level, compactness, basic floor space, floor space, a garage, height of premises, volume of height, exterior, harmfulness of used building materials, sound insulation properties of walls, fire resistance (see Table 9).

Table 9

Complex determination of the importance of the criteria of dwelling alternatives taking into account their quantitative and qualitative characteristics

Decision making matrix									Determination of		
Criteria under evaluation	Measuring units of criteria	*	Numerical values of criteria of the compared single-family dwellings					Initial importance of criteria, p_i	Sum of criteria, S_i	Total monetary expression of criteria, P_i	Importance of criteria, q_i
			1	2	3	4	5				
Quantitative criteria											
1. Estimated cost	1000 Lt	–	329,657	611,413	418,708	345,485	343,477	1	2048,740	2048,740	0,8797
2. Annual expenditure of comparative fuel for heating a building	T/Year	–	2,99	4,03	3,14	2,62	2,79	50	15,57	280,260	0,1203
											V = 2329,000
Qualitative criteria											
3. Physical longevity	Year	+	50	100	100	50	50	0,132	–	–	0,1161
4. Comfort level	Points	+	7,80	9,73	8,67	8,00	5,73	0,285	–	–	0,2507
5. Compactness	Points	+	8,40	4,87	9,40	9,00	7,00	0,031	–	–	0,0273
6. Basic floor area	Points	+	10,00	1,00	7,00	9,00	10,00	0,178	–	–	0,1566
7. Floor area	Points	+	9,00	1,00	8,00	10,00	9,00	0,103	–	–	0,0906
8. A garage	Points	+	10,00	10,00	9,00	8,00	6,00	0,071	–	–	0,0625
9. Height of premises	Points	+	9,67	9,33	9,67	9,33	9,33	0,043	–	–	0,0378
10. Volume of height	Points	+	8,67	7,47	8,93	9,40	6,87	0,082	–	–	0,0721
11. Exterior	Points	+	6,80	8,80	9,60	9,33	7,00	0,021	–	–	0,0185
12. Harmfulness of used building materials	Points	–	1,00	6,00	6,00	2,00	1,00	0,140	–	–	0,1232
13. Sound insulation properties of walls	Points	+	10,00	10,00	10,00	10,00	10,00	0,059	–	–	0,0519
14. Fire resistance	Points	–	4,00	3,00	3,00	4,00	4,00	0,075	–	–	0,0660

* The sign z_i (+ (–)) indicates that a greater (less) criterion value corresponds to a greater importance for a client.

For better understanding of the stated above, let us make a comparison of the 1st alternative with the 2nd one (see Table 10). The cost of dwelling in the 1st version is lower while annual expenditure of comparative fuel for heating, compactness, basic floor space, floor space, height of premises, volume of height, harmfulness of used building materials of this version are more favourable. The 2nd alternative, however, differs from the 1st one in possessing better quality characteristics (i.e., physical longevity, comfort level, exterior, fire resistance).

As can be seen from Table 9, each criterion goes together with its measurement unit and importance. The magnitude of importance indicates how many times one criterion is more important than the other one in a multiple criteria evaluation of building life cycle. For example, in the evaluation of comfortability importance by computer-aided calculations, it was obtained that $q_4 = 0.2507$, what is 4.83 ($q_4 : q_{13} = 0.2507 : 0.0519 = 4.83$) times more important for inhabitants than the conveniences originating from wall sound insulation (importance $q_{13} = 0.0519$). The calculations revealed that the key factors which have affected the efficiency of single-family dwellings are (see Table 9): estimated cost of building ($q_1 = 0.8797$); comfort level ($q_4 = 0.2507$); basic floor area ($q_6 = 0.1566$); harmfulness of used building materials ($q_{12} = 0.1232$); annual expenditure of comparative fuel for heating a building ($q_2 = 0.1203$), etc. The results of a multiple criteria evaluation of 5 dwelling versions are presented in Table 10. From the

Table 10

Dwelling alternatives multiple criteria analysis results and determination of the priority and utility degree of alternatives

Criteria under evaluation	Measuring units of criteria	*	Importance of criteria	Weighted normalized values of criteria of the compared variants				
				1	2	3	4	5
1. Estimated cost	1000 Lt	–	0,8797	0,1415	0,2625	0,1798	0,1483	0,1475
2. Annual expenditure of comparative fuel for heating a building	T/Year	–	0,1203	0,0231	0,0311	0,0243	0,0202	0,0216
3. Physical longevity	Year	+	0,1161	0,0166	0,0332	0,0332	0,0166	0,0166
4. Comfort level	Points	+	0,2507	0,0490	0,0611	0,0544	0,0502	0,0360
5. Compactness	Points	+	0,0273	0,0059	0,0034	0,0066	0,0063	0,0049
6. Basic floor area	Points	+	0,1566	0,0423	0,0042	0,0296	0,0381	0,0423
7. Floor area	Points	+	0,0906	0,0220	0,0024	0,0196	0,0245	0,0220
8. A garage	Points	+	0,0625	0,0145	0,0145	0,0131	0,0116	0,0087
9. Height of premises	Points	+	0,0378	0,0063	0,0061	0,0063	0,0061	0,0061
10. Volume of height	Points	+	0,0721	0,0120	0,0103	0,0124	0,0130	0,0095
11. Exterior	Points	+	0,0185	0,0030	0,0039	0,0043	0,0042	0,0031
12. Harmfulness of building materials	Points	–	0,1232	0,0077	0,0462	0,0462	0,0154	0,0077
13. Sound insulation properties of walls	Points	+	0,0519	0,0104	0,0104	0,0104	0,0104	0,0104
14. Fire resistance	Points	–	0,0660	0,0147	0,0110	0,0110	0,0147	0,0147
The sums of weighted normalized maximizing indices of variant S_{+j}				0,1821	0,1496	0,1898	0,1810	0,1596
The sums of weighted normalized minimizing indices of variant S_{-j}				0,1870	0,3508	0,2612	0,1986	0,1914
Importance of variant Q_j				0,4674	0,3017	0,3941	0,4496	0,4384
Priority of variant				1	5	4	2	3
Utility degree of the project Nj (%)				100	64,55	84,32	96,19	93,80

Table 10 it is seen that the first version is the best in the utility degree which equals 100%. The second version was the fourth according to priority (its utility degree was equal to 96.19%).

Multiple criteria analysis of solutions dealing with plots of land, contractors, dwelling maintenance was carried out in a similar way as that of the dwellings. Further complex multiple criteria analysis of building life cycle was based on three best solution versions (see Table 12) chosen separately for various solutions. For example, dwellings top priority versions are correspondingly 1, 4 and 5 (see Table 10) while those plots of land are 3, 5 and 4 (see Table 11).

In order to design and realise an efficient building life cycle, it is necessary to carry

Table 11

Plot alternatives multiple criteria analysis results and determination of the priority and utility degree of alternatives

Criteria under evaluation	Measuring units of criteria	*	Importance of criteria	Weighted normalized values of criteria of the compared variants				
				1	2	3	4	5
1. Price of a plot of land	Lt/m^2	–	0,4369	0,1663	0,1109	0,0554	0,0637	0,0406
2. Engineering networks	Points	+	0,2153	0,0501	0,0501	0,0501	0,0501	0,0150
3. Telephone	Points	+	0,0297	0,0059	0,0059	0,0059	0,0059	0,0059
4. Recreational opportunities	Points	+	0,0256	0,0062	0,0010	0,0083	0,0083	0,0017
5. Roads and access opportunities	Points	+	0,0315	0,0112	0,0092	0,0040	0,0040	0,0030
6. Dwelling territory	Points	+	0,0289	0,0072	0,0076	0,0056	0,0056	0,0029
7. Neighbours	Points	+	0,0230	0,0055	0,0057	0,0044	0,0045	0,0028
8. District prestige	Points	+	0,0259	0,0071	0,0069	0,0055	0,0055	0,0007
9. Opportunities of development of a district	Points	+	0,0177	0,0062	0,0056	0,0026	0,0026	0,0006
10. Volume of a plot of land	Points	+	0,0378	0,0078	0,0088	0,0063	0,0063	0,0086
11. Configuration of a plot of land	Points	+	0,0340	0,0080	0,0082	0,0063	0,0048	0,0067
12. Position of a plot of land in respect of other plots	Points	+	0,0469	0,0113	0,0096	0,0066	0,0097	0,0097
13. Properties of ground	Points	+	0,0253	0,0053	0,0053	0,0047	0,0047	0,0053
14. Air pollution	Points	–	0,0215	0,0215	0,0000	0,0000	0,0000	0,0000
The sums of weighted normalized maximizing indices of variant S_{+j}				0,1319	0,1239	0,1106	0,1122	0,0631
The sums of weighted normalized minimizing indices of variant S_{-j}				0,1878	0,1109	0,0554	0,0637	0,0406
Importance of variant Q_j				0,1648	0,1802	0,2237	0,2105	0,2208
Priority of variant				5	4	1	3	2
Utility degree of the project Nj (%)				73,68	80,53	100	94,07	98,69

Table 12

Most efficient solution alternatives set according their priorities

Solutions considered	Priority of the best alternative solutions		
	1	2	3
1. Plot variants	3	5	4
2. Single-family dwelling variants	1	4	5
3. Contractor variants	1	3	2
4. Maintenance variants	1	2	3

out an exhaustive investigation of all solutions to be made. The versions of a building life cycle are formed by choosing different solutions. The versions of building life cycle are formed using the initial data (see Tables 8 and 9). In the process of forming possible versions the compatibility of separate variants of life cycle is taken into account.

Solutions of an alternative character allow for more rational and realistic assessment of economic, social conditions and traditions and for better satisfaction of architectural, comfort, functional, maintenance and other customer requirements. Their application also enables to cut down project costs. As initial data and variable project parameters are changing, so are the values and importance of criteria characterising them.

The prepared building life cycle versions are assessed according to different requirements. A version not corresponding to these requirements is stricken out and not considered any more.

Further on, after the formation of decision making matrix, the possible most rational versions of a building life cycle are determined and grouped according to their priority. This is done using the above methods of multiple criteria analysis. Then the investigation of building life cycle is continued. On the basis of the performed analysis of versions, for instance, it is possible to determine the utility degree of the investigated projects.

The greater is the priority of version the higher is the efficiency of the building life cycle. Importance Q_i of a project indicates satisfaction degree of demands and goals pursued by clients – the greater is the Q_i the higher is the efficiency of the building life cycle. In this case, the importance $Q_{\max}$ of the most rational project will always be the greatest. The importance of all remaining projects is lower as compared with the most rational one. This means that demands and goals of interested parties will be satisfied to a lesser extent than it would be in case of the best building life cycle.

The utility degree of 1st version is $N_1 = 100\%$, i.e., the building life cycle being examined as per the established is more in conformity to purposes and needs of a client nor other variants.

Results acquired within calculation show that the first variant of the building life cycle as per established conditions of a task is more in conformity with purposes and needs of a client nor other variants. In such case analysis of the building life cycle has been made from positions of a client (further user). However, taking into consideration the acquired results, various participants of the building's life cycle (designers, building material manufacturers, suppliers, contractors, users, finansing institutions, local government, etc.) may also adjust their to be made decisions in accordance with attached priorities and present situation.

8. Conclusions

Formalized presentation of the research shows how changes in the environment and the extent to which the goals pursued by various interested parties are satisfied cause corresponding changes in the utility degree of a building life cycle. With this in mind, it is possible to solve the problem of optimization concerning satisfaction of the needs at reasonable expenditures. This requires the analysis of building life cycle versions allowing to find an optimal combination of goals pursued and finances available.

Multiple criteria analysis of the building life cycle allows evaluating how economic, technical, qualitative (architectural, aesthetic, comfortability), technological, social, legislative, infrastructural, technical and other decisions are in conformity with needs and opportunities of clients, designers, contractors, users, and other participants of this process. These needs are expressed through the systems, values of quantitative and qualitative criteria, importance of criteria.

References

Arditi, D., H.M. Gunaydin (1998). Perception of process quality in building projects. *Journal of Management in Engineering*, **15**(2), 43–53.

Arditi, D., B.K. Patel (1989). Expert system for claim management in construction projects. *International Journal of Project Management*, **7**(3), 141–146.

Bana E Costa, C.A., E.C. Correa (1998). A multicriteria evaluation of proposals for constructing a new subway in Lisbon. In *47^{th} Meeting of European Working Group "Multicriteria Aid for Decisions"*, Thessaloniki, 26–27 March 1998. Abstracts and papers. Technical University of Crete, Greece. pp. 25–32.

Bana E Costa, C.A., J.-Cl. Vasnick (1997). A theoretical framework for measuring attractiveness by categorical based evaluation techniques (MACBETH). In *Multicriteria Analysis*. Springer-Verlag, Berlin. pp. 15–24.

Chinyio, E.A., P.O. Olomolaiye, P. Corbett (1998). Quantification of construction clients' needs through paired comparison. *Journal of Management in Engineering*, **14**(1), 87–92.

Dupagne, A., P. Mathus (1998). CABMAS (Computer aided building management system): development of an integrated computerised platform for the management of information flows adapted to small and medium size building companies. In B.-C. Bjork, A. Jagbeck (Eds.), *The Life-Cycle of Construction IT Innovations – Technology Transfer from Research to practice*. Royal Institute of Technology, Stockholm. pp. 179–190.

Goicoechea, A., R.W. Nelson, W. Truszkowski (1987). A decision-support system for systems engineering and management. In *Toward Interactive and Intelligent Decision Support Systems*, Vol 2. Springer-Verlag, Kyoto. pp. 71–79.

Kalay, Y.E., L. Khemlani, J.W. Choi (1998). An integrated model to support distributed collaborative design of buildings. *Automation in Construction*, **7**(2, 3), 177–188.

Ozernoy, V.M. (1992). Developing an interactive decision support for discrete alternative MCDM method selection. In *Multiple Criteria Decision Support*. Springer-Verlag, Berlin. pp. 242–257.

Ozernoy, V.M. (1987). A framework for choosing the most appropriate discrete alternative multiple criteria decision making method in decision support systems and expert systems. In *Toward Interactive and Intelligent Decision Support Systems*, Vol 2. Springer-Verlag, Kyoto. pp. 56–64.

E.K. Zavadskas Doctor Habil, Professor, Rector of Vilnius Gediminas Technical University (Lithuania). Member of Lithuania Academy of Sciences, Member of Ukrainian Academy of Technological Cybernetics.

In 1973 Dr degree in building structures. Assistent, Senior Assistent, Associate Professor, Professor at the Department of Construction Technology and Management. In 1987, Dr Habil at Moscow Civil Engineering Institute (building technology and management). Research visits to Moscow Civil Engineering Institute, Leipzig and Aachen Higher Technical Schools. He maintains close academic links with the universities of Aalborg (Denmark), Salford and Glamorgan (UK), Poznan University of Technology (Poland), Leipzig Higher School of Technology, Economics and Culture (Germany). Member of international organisations. Member of organisational and programme committees of many international conferences. Member of editorial boards of some research journals. Author of monographs in Lithuanian, English, German and Russian. Research interests: build-

ing technology and management, decision-making theory, automation in design, expert systems.

A. Kaklauskas Doctor Habil, Professor, Chairman of Department of Construction Technology and Management, Vilnius Gediminas Technical University (Lithuania). In 1984 graduate of Vilnius Civil Engineering Institute, he obtained his doctorate at Dnepropetrovsk Civil Engineering Institute (1990) and habil doctorate at Vilnius Gediminas Technical University (1999). Spheres of current research: analysis, modelling and forecasting of housing credit access; multiple criteria decision making methods; multiple criteria decision support systems; total quality management; total life analysis, modelling and forecasting of construction in Lithuania; total life analysis, modelling and forecasting of housing in Lithuania; facilities management. Author of 62 research publications in Germany, United Kingdom, Denmark, Portugal, Greece, Poland, Rumania, Lithuania, former Soviet Union. Among them there are 4 monographs.

N. Kvederytė Doctor, Associate Professor, Department of Construction Technology and Management, Vilnius Gediminas Technical University (Lithuania). A graduate of Vilnius Gediminas Technical University, civil engineer (1993), MSc (1995), PhD (civil engineering, 2000). Main research interests: building life cycle, multiple criteria decision-making, decision support systems.

Pastato gyvavimo proceso alternatyvusis projektavimas ir daugiakriterinė analizė

Edmundas Kazimieras ZAVADSKAS, Arturas KAKLAUSKAS, Nerija KVEDERYTĖ

Alternatyvusis projektavimas ir daugiakriterinė pastato gyvavimo proceso analizė leidžia įvertinti, kaip ekonominiai, architektūriniai, tūriniai, planiniai, techniniai, technologiniai ir kiti sprendimai atitinka pastato gyvavimo proceso dalyvių (užsakovų, projektuotojų, rangovų, naudotojų ir kt.) reikalavimus ir galimybes. Šie reikalavimai yra išreiškiami per kiekybinių ir kokybinių kriterijų sistemas, kriterijų svarba yra įvertinama reikšmingumų pagalba.

Pastato gyvavimo proceso variantams sudaryti yra sukurtas naujas projektų daugiakriterinio alternatyviojo projektavimo metodas. Siekiant sumažinti informacijos apimtį, naudojamą pastato gyvavimo proceso automatizuoto alternatyvaus projektavimo metu, įvedami alternatyvų kodai. Kodai su jų teikiama koncepcine ir kiekybine informacija yra naudojami visoms pastato gyvavimo proceso sprendimų alternatyvoms apibūdinti.

Pastato gyvavimo proceso efektyvumo lygis priklauso nuo daugelio jį veikiančių kiekybinių ir kokybinių kriterijų. Straipsnyje pateikiamas autorių sukurtas kompleksinis kriterijų reikšmingumo nustatymo metodas, kuris leidžia apskaičiuoti ir tarpusavyje suderinti kiekybinių ir kokybinių kriterijų reikšmingumus, atsižvelgiant į analizuojamas pastato gyvavimo proceso kiekybines ir kokybines charakteristikas. Taip pat straipsnyje pateikiamas projektų daugiakriterinio kompleksinio proporcingo įvertinimo metodas. Taikant pasiūlytą projektų daugiakriterinio kompleksinio proporcingo įvertinimo metodą, apskaičiuojamas santykinis reikšmingumas, kuris įvertina lyginamų kriterijų reikšmių ir reikšmingumų santykinę įtaką pastato gyvavimo proceso (atskirų jo sprendimų) kompleksiniam efektyvumui. Straipsnyje pateikiami taikant šiuos metodus išspręsti konkretūs uždaviniai.