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Multi-criteria evaluation of building sustainability behavior

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Abstract

Building's functioning coherence is important characteristic which influence not only the design, building works, management, input size, but also the choice of housing and living safety, and ease of implementation of the decisions. Coherence evaluation models listed in scientific and special literature are based on the valuations made by several different criterions or aspects of the building's functioning coherence are not connected by presented criterions. There is no single summarizing indicator which would cover all the aspects of the building's functioning coherence and would allow to valuate coherence. The purpose of this article is to present the method to evaluate the building's functioning coherence. Based on analysis it is proven that coherence evaluation is attributable to the category of multi – criteria tasks. In this article the presented building's functioning coherence methodology refers to multi – criteria evaluation model "Copras" which is based on selected and justified 11 criterions. It also includes recommendations for the professional evaluation based on mentioned criterions.

Keywords: sustainability; multi-criteria evaluation; model; expert method.

1. Introduction

Sustainable development is an aspiration of numerous recent activities and the main topic of scientific research. In scientific sources, projects and leaflets we find an increasing use of phrases "sustainable development", "sustainable living environment", "sustainable urbanism", etc. More and more often the literature presents only generalized models of the activities, the cultural- psychological aspect on residents health and the solutions of welfare problems are not taken into account, the information presented is shaded by a discussion and dry data on

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the latest technologies meant to ensure the ecology or improve energy efficiency of buildings or discuss the resources saving policies. It has been noticed that questions related to the sustainable development of buildings are often analyzed at the macro- building set level. Examination at this range makes it complicated to tell where and what decisions at micro- (one building) level have to be taken to ensure a positive influence of every decision on the inhabitant environment quality and development.

In the twentieth century the rapidly developing technology allowed growth in the construction volume. Therefore cities expanded the density of the buildings increased and the number of people living and working in the cities grew. In order to reach a balance which was shattered when people from remote locations came to live in the city, a faster development of sustainable approaches to the construction area was introduced. Together with innovative technologies in modern buildings there is a tendency to renew projects for maximized use of original spaces which require little investment. An important place among them went to decisions oriented to community and social well-being development implementation possibilities. Though more investment is needed for the implementation of innovative decisions, opportunities for energy saving and lower CO_2 emissions open in the future perspective.

The aim of the article is to present an innovative building sustainability behaviour evaluation methodology for the buildings' buyers and users and give them an opportunity to establish the value of the buildings with the help of quantitative methods from sustainability point of view. The method can be used not only for sustainability evaluation of a block of flats but also for sustainability evaluation of buildings for other purposes (industrial, agricultural, sports, etc.) To achieve the goal the following tasks must be solved:

- To define the concept of sustainability by learning about its goals and principles;
- To survey the current methodological potential for a building sustainability evaluation, estimate the methods' application possibilities in respect of modern consumer needs;
- To suggest an innovative model for an integrated assessment of a building sustainability behaviour with the help of quantitative indicators.

The subject of research in this article is a building sustainability behaviour evaluation process, the results of which would allow to establish the value of buildings.

2. Aims and Principles of Sustainability

Sustainable development is perceived as a society development process which will allow an opportunity to achieve the welfare of present generations without compromising the ability to do so for future generations, combining environmental, economic and social aspirations of the society and within the permissible limits of environmental impact (Cole, 1999). It is quite clear that the goal of sustainable development is to reconcile economic growth, social progress and sustainable use of natural resources, maintaining the ecological balance and ensure favourable living conditions now and in the future.

The concept of sustainable development can be summarized a as a process of creating a healthy environment, a vibrant economy, social welfare and an active community. Nevertheless, the negative impact of people's activity on the environment in which the buildings are constructed and updated must be minimized.

Building renovation is a good way to reduce the building energy needs, as well as develop other sustainable development principles, the basic and equal components of which are ecological, economic and social (Mickaitytė, 2008). Building renovation means its reconstruction when worn parts are replaced or new systems are integrated. From the modern consumer point of view these actions are purposeful only when the sustainability principles are implemented for the improvement of the functioning of the building (building behaviour).

Alawar (2010) explains a building as a sustainable framework made of three parts: its people, products and processes. This approach must be followed therefore in recent years more and more organizations devote a great deal of investment to apply sustainable development, focusing on sustainable building renovation in an effort to reduce energy consumption and CO2 volumes, as well as to community revitalization with the help of various means. With this purpose leaders of organizations need the measurement of sustainability to enable them compare sustainability indicators of the given building with, for example, the ones of their competitors' (or other companies') building sustainability indicators. Renovation of the buildings built in the previous century and integration of multiservices into the building space of new sustainable buildings is an increasingly significant challenge faced by both - purchasers of the building, as well as building operators and builders, emphasizing sustainability as one of the major needs for living or any other activities

3. Discussion on the suitability of a building sustainability evaluation methods

Buildings make a large and ever-increasing impact on the environment (Castro-Lacouture, 2009). During the life of a building a lot of energy and financial resources are consumed. The sustainable development topic today comes up again and again in an effort to ensure a more efficient use of energy and protection of environment, building sustainability assessment systems are applied to encourage a careful consideration of the planning, design, construction and building operation management processes (Chau, 2010). This allows a reduction of costs and impact on the environment, also to boost the quality of the buildings and increase their market value.

As mentioned by Burnett (2007), cities and their inhabitants consume the biggest part of energy and they make a huge influence on the climate change, on the other hand they play an important role in the process of achieving sustainability in the world. In recent years several research papers have been presented for effectiveness evaluation of energy consumption and other indicators (Aberg & Henning 2011; Dalla Rosa & Christensen 2011). Burnett (2007) made attempts to evaluate sustainability from the economic point of view. His choice of economic – financial indicators (initial investment, return on investment, project value) is worth attention but the application of them alone does not give a full picture of a building sustainability.

Other applied and recognized environmentally friendly building evaluation methods and systems emphasize only energy saving or enhancing the effectiveness of water usage, CO2 emissions reduction or improved quality of life, planning and purposeful use of resources. Other commonly used building sustainability assessment methods are: BREEAM (2008, UK), Leeds (1998, USA), BEAM Plus (1996, Hong Kong) SBTool (1995 International) CASBEE (2004, Japan) BEPAC (1993, Canada).

The BREEAM method of building sustainability assessment is exceptional in the sense of result objectivity and is the most advanced therefore applied in many countries. The method is based on the elimination of inaccuracies of previously developed and applied methods and on increased usage precision. It is therefore appropriate to examine the circumstances of this approach. BREEAM is a leader in building sustainability assessment, with separate versions for the evaluation of different building types, so its applicability is very broad. E.g., the criteria for blocks of flats assessment will give more accurate results than generic ones, intended to evaluate the sustainability of any type of building. This method allows an easy adaptation of the criteria to the country climatology and legal framework. Although BREEAM method has been globally recognized as one of the leaders in the field, this expert approach is based on assessment of qualitative indicators, so it is not objective enough, therefore the outcome depends on the qualification of the experts and other uncertain factors.

But it is an innovative approach which is based on the assessment by 10 criteria, grouped according to the aspects of sustainability (Table 1).

The application of other methods mentioned before is based on evaluation by one or just a few criteria. A bigger number of criteria enhance the objectivity of the evaluation. Another advantage of BREEAM 2008 method over the others is the possibility to evaluate the significance of the criteria (Ustinavičius, 2012).

However, BREEAM 2008 assessment method does not reveal the feature of the evaluation result complexity which is a must for sustainability evaluation, it classifies the assessment criteria, which when taken separately give the experts a possibility to assess the building sustainability on each of them and make a joint decision. So, experts' participation in the process of sustainability evaluation will be desirable, because some of criteria can be qualitative, which determination of value and significance is prerogative for them.

However, it should be noted that the wording of a number of multi-criteria (Table 1) is not appropriate in the description of BREEAM method and may be difficult to understand, therefore it should undergo correction. According some criterion result can be satisfactory or sometimes even good and according other – unsatisfying. So, our opinion is that BREEAM 2008 method cannot answer, which solution is the best in existing conditions and present situations and it is need better instrument for assessment sustainability of building behavior.

Table 1. Criteria groups of BREEAM 2008 method

Management:	**Materials:**
Possibility of control	Construction elements
Professionalism of constructors	Using the façade of the building
Building site impact	Using the existing solutions of the building
Building consumer guide	Rational use of materials
Possibility consulting	Insulation
Safety	Ensuring fortitude
Health and welfare:	Decorating items
Natural lighting	**Waste:**
View through the window	Construction waste management
Privacy	Recycled materials
High – frequency lighting	Recyclable waste storage
Internal and external lighting levels	Composting
Natural ventilation	**Land use and ecology:**
Volatile organic compounds	Contaminated soil
	Ecological value and protection of biological characteristics
Possibility of heat regulation	Ecological footprint reduction
Microbial contamination	Plot ecological improvement
Suitability of external environment	Long-term impact on biodiversity
Office fit	**Pollution:**
Sound insulation	Refrigerant global warming potential
Energy:	Refrigerant leaks
Reduction of CO_2 emissions	Heating sources No_x emissions
Detailed energy accounting	Flood risk
External lighting	Plumbing pollution reduction
Low CO_2 emitting technologies	Night light pollution reduction
Energy saving devices	**Transport:**
Drying spaces	Possibility to use public transport
Innovations:	Infrastructure
Responsible builders	Facilities for cyclists
Daylight	Pedestrian and cyclist safety
Reduction of CO_2 emissions	Car parking places
Low CO_2 emitting technologies	**Water:**
Water meter	Water consumption
Conscious material supply	Water meters
Site waste management	Water leakage detection
Rating by the BREEAM professional	Water recycling

It is possible to recognize greater objectivity of the evaluation results when compared with other methods. It is require noting, that BREEAM 2008 method is positive, that it demand using significance of the criteria (Table 2). In addition, some of the criteria for inclusion (e.g., responsible builders, conscious material supply, etc.) cast some doubt as to their practical utilization.

Table 2. Significance of BREEAM 2008 method criteria groups, %

No	Name of criterion	Significance, %
1	Management	12
2	Health and welfare	15
3	Energy	19
4	Transport	8
5	Water	6
6	Materials	12.5
7	Waste	7.5
8	Land use and ecology	10
9	Pollution	10
10	Innovations	10

We can declare that the criteria have been chosen properly, they fully reflect the essence of sustainability. However, the omission of economic-financial criteria group can be seen as a drawback. Assessment following this group of criteria goes with the principles of sustainability therefore we cannot omit this criteria group. If this deficiency is eliminated, the objectivity of the application of the method could increase.

Some of the suggested criteria are minimizing, others are maximizing. If we disregard this factor we might be faced with the possibility of not receiving objective results. It is therefore appropriate to say that the universally accepted and currently the most widely used BREEAM method applied for measuring building sustainability has some imprecision and uncertainty in its characteristics and is not the best instrument for measuring building sustainability behaviour.

To prevent the mentioned inaccuracies and uncertainties it is appropriate to use any of the multi-criteria assessment methods which would allow combining a variety of criteria estimates into a single score. According to this result sustainability indicators of several buildings could be compared and would enable to get objective comparable indicators for building sustainability evaluation. After all it is obvious that building sustainability behaviour evaluation belongs to the category of multi-criteria tasks (Buchholz, 2009). Ginevičius and Podvezko (2008) widely explained possibilities of multi-criteria assessment of social phenomena. They explained using of methods suitability according different situations and circumstances. Čiegis and Ramanauskienė (2011), Nussbaumer (2009) even suggest appliance of multi-criteria methods for assessing sustainability. They did not suggest real criteria for assessing, but approve for appropriateness of these methods. Pabedinskaitė and Vitkauskas (2011) preferred multi-criteria assessment for evaluating product quality. Sustainability of any product can be one of its criteria of quality. So, they agree for using of multi-criteria methods also.

4. Application of the Multi-criteria Evaluation Method

To sum up the essence of BREEAM method, it can be said that the advantage of the method is determined by the use of a number of different criteria and criteria weights' dimension for assessment. It has already been mentioned that building sustainability behaviour evaluation belongs to the category of multi-criteria tasks. So, the question is which multi-criteria assessment method is the best for establishing a value of this category. A review of a number of assessment methods' options leaves us with Copras multiple criteria evaluation approach proposed by Malinauskas, Kalibatas (2005), Bivainis, Drejeris (2009) which would provide a simple way to measure building sustainability. By the way, Malinauskas, Kalibatas (2005) unambiguously state that the use of Copras method for the construction activities will undoubtedly produce a more objective result. Ginevičius and Podvezko (2008) also do not contradict for its using, but only explain its suitability.

So, stage 1 of Copras method foresees a justification of the evaluation criteria selection. It is appropriate to use BREEAM method evaluation criteria, having evaluated their application and adding the missing components to the set.

The second step of this method is the establishment of the relative importance of the criteria. The importance of the criteria is scientifically substantiated in BREEAM method application manual, so they are appropriate for the proposed assessment, only the newly introduced criteria groups' proportional recalculation in this case is necessary.

An innovative (modified) methodology is offered which is based on expert assessment scores for a restricted number of points.

The following step is the standard Copras method application procedures: standardized estimates matrix formation, then ranking of alternatives and setting of the most appropriate (Fig. 1).

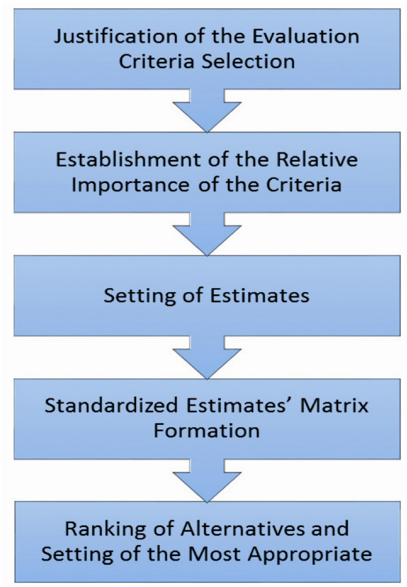

Fig. 1. Suggested building evaluation model

The proposed method provides ample opportunity (while analyzing the results) to find the best option for different criteria and facilitate the assessment work when it is necessary to prioritize tasks. Malinauskas and Kalibatas (2005: 198) state that when the multi-criteria method is used the results speak for themselves: in construction, for example, while assessing technology, "in an only aspect, the project is often selected 30–40% of inferior quality, while the multi-criteria evaluation costs for improving the quality make only 10–15%". The authors of the article advocate for Copras method.

4.1. Justification of the Evaluation Criteria Selection

BREEAM method of building sustainability assessment is accurate enough in terms of management, health and wellness, energy, transport, water, materials, waste, land use and ecology, pollution and innovation evaluation separately. It must be recognized that groups of criteria and separate criteria have been selected appropriately and rationally, and they fully reflect the essence of sustainability. However, by supplementing BREEAM evaluation method by a set of criteria with a group of economic-financial criteria, we could get the full range of criteria, the usage of which would give a complete and objective result of building sustainability. In addition, the afore mentioned incorrectly specified criteria in BREEAM method User Manuel should be altered as to more precisely define the essence of sustainability. For example, the criteria of the innovation group of criteria should be corrected while adding more innovative ones: solar modules' integration options, wind power integration options, application possibilities of coolness production devices. Zavadskas (1999) also suggests criteria for assessment sustainability, but set of them can be supplemented according contemporary requirements of building behavior. Some contemporary criteria for waste assessment are suggested by Gorsevski (2012), which are included in the set for assessing waste. So, after the some correction a new set of building sustainability behavior assessment criteria has been presented as follows:

Suitability of management (possibility of the on-going work control, suitability of work planning, intelligibility of a building usage manual).

Appropriateness of **materials** (Quality of construction elements, innovations using in building constructional solutions, rational use of materials, Quality of insulation, reliability of fortitude ensuring, Quality of decorating items).

Health and welfare (Natural lighting view through the window, privacy, high frequency lighting, internal and external lighting levels, natural ventilation, indoor air quality, quantity of volatile organic compounds, thermal comfort, heat regulation, microbial contamination, the external environment, humidity regulation, sound insulation).

Waste (suitability of construction work management, recycled material %, recyclable waste storage needs, composting possibilities, compost sorting development category).

Land usage and ecology (Vacant plot space utilization, soil contamination, and degree of protection of ecological value and ecological characteristics, ecological footprint reduction opportunities, plot ecology improvement possibilities, long term impact of biodiversity).

Energy (building leakage, detailed energy consumption accounting, duter lighting, low CO_2 emitting technologies, reclamation of energy saving devices, drying places).

Pollution (refrigerant global warming potential, refrigerant leakage probability, heating sources of NOx emissions category, sound pollution, plumbing pollution, night light pollution).

Convenience of transport (infrastructure development, cyclist amenities, pedestrian and cyclist safety, car parking places).

Water availability (water consumption, sate of water meters, possibility of water leakage detection, possibility of water recycling, water quality).

Possibilities or using of innovations (solar modules' integration options, wind power integration options, coolness production devices application possibilities).

Economical–financial criteria (need for initial investment, return on investment, project value, expenditure of exploitation).

Copras multi-criteria evaluation method application result would be even more objective and would allow an opportunity to compare the sustainability of several buildings and could have a wider practical application. With the aim to insert the economic-financial criteria in BREEAM method set of criteria it would be appropriate to remember Burnett (2007) economic-financial indicators (initial investment, return on investment, project value) and form a separate group on the basis of the criteria. Expenditure of exploitation also is significant indicator of sustainability (Kajikawa & Inoue, 2010). Mao and others (2009), Sinoe and Kyvelou (2006) who did the analysis of sustainable building assessment methods found out that the main sustainable building assessment tools usually focus on the environment protection and do not include significant economic issues. Kajikawa, Inoue (2010) agree on the inclusion of the above criteria in the overall set of criteria, and specify that the economic-financial criteria should be viewed in parallel with those of environment protection. In conclusion, it is appropriate to add the economic-financial criteria cluster to the 10 existing sets of criteria.

4.2. Determination of Criteria Relative Significance η

Relative significance of criteria is presented in the description of BREEAM method (Table 2) which is appropriate to use when applying the suggested Copras method. We would like to draw your attention to the fact presented by Mickaitytė and co-authors (2008) that the main components of sustainability are equivalent – ecological, economic and social (Mickaitytė, 2008). Since it was suggested to include the group of economic-financial criteria, the significance of BREEAM criteria had to be recalculated to achieve, an equivalent ratio with other criteria groups. BREEAM set of criteria groups was supplemented by the insertion of the economic-financial criteria group, and giving to it a certain relatively corrected significance index (Table 3).

Table 3. Significance indicators of suggested criteria groups, %

No	Name of criterion	Significance, %
1	Management	10.00
2	Health and welfare	12.50
3	Energy	15.83
4	Transport	6.67
5	Water	5.00
6	Materials	10.42
7	Waste	6.25
8	Land use and ecology	8.33
9	Pollution	8.33
10	Innovation	8.33
11	Economic- Financial	8.33

The proposed economic-financial group criteria (initial investment, return on investment and project value) are valuable because absence of the project financial evaluation reduces its usefulness and effectiveness and increases uncertainty for consumers, which lessens their interest in a selected building (Kajikawa & Inoue 2010).

4.3. Establishment of Estimates

Since relative significance of criteria groups is presented rather than the relative significance of individual criteria, so in order to facilitate the work of the experts and to more precisely determine detailed estimates of a criterion it is proposed to provide 100 points for each group of criteria and divide them between the separate criteria. In this way, there is an opportunity for some detailed criteria to modify the significance dimension and further increase the accuracy of the assessment, depending on the particular situation. This innovative approach to the determination of estimates will undoubtedly increase the objectivity of the evaluation, and may even serve the promotion of building sustainability behavior.

4.4. Formation of normalized values' matrix

The suggested criteria (Table 4) are presented in various dimensions, so in an effort to establish the criteria for comparability there is a need to convert into the right amount of unprecedented dimension. This can be done by using the following formula (Zavadskas,1999; Ginevicius, 2008):

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

where: x_{ij} –j building behaviour estimate from the criterion i; m – number of criteria; η_i – i criterion significance; n – the number of comparable buildings.

The sums (S) of normalized estimates for one of the buildings (j) under assessment following maximizing (the higher the value the better the option) and minimizing (the lower the value the better the option) criteria are calculated as follows:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}, j = \overline{1,n} \tag{2}$$

Relative significance of the buildings under investigation is determined by minimizing and maximizing the sums of normalized criteria values using the following formula (Zavadskas, 1999):

$$Q_j = S_{+j} + \frac{S_{-min}\sum_{i=1}^{n} S_{-j}}{S_{-j}\sum \frac{S_{-min}}{S_{-j}}}, j = \overline{1,n} \tag{3}$$

Options of analyzed buildings are ranked in the order of relative importance index Q_j values. For the convenience of the evaluators it is recommended to present calculation results in the form of a normalized value matrix,, as is given in Table 4.

Table 4. Normalized value matrix

Criteria	Direction of a criterion	Significance	Normalized values of estimates			
i_1		η_1	D11	D12	…	D1n
i_2		η_1	D21	D22	…	D2n
…		…	…		…	…
i_{11}		η_{11}	D111	D112	…	D11n
Sum of normalized maximizing indicators			S+1	S+2	…	S+n
Sum of normalized minimizing indicators			S-1	S-2	…	S-n
Relatives importance of comparable variants			Q1	Q2	…	Qn
Range of sustainability						

The result based on the calculation results comes in a tabular form (Table 4): it is possible to compare sustainability behavior of two (or more) buildings. While analyzing these data, each buyer could obviously choose a better building with respect to the whole set of criteria and without going deep into the evaluation of individual parts of the assessment also not losing focus of his main goal – to acquire a more sustainable building. For the building operator it is easy to evaluate the building sustainability behavior when comparing with similar qualities of other buildings.

5. Conclusions

1) The aim of sustainable development is to reconcile economic growth, social advances use natural resources economically, maintain ecological balance and guarantee favorable living conditions for the present and future generations. The challenges are also characteristic of an appropriate building behavior (functioning of a building).

2) A review of building sustainability behavior assessment methodological potential has shown that most of the methods and models for evaluating sustainability used one (most often ecological) criterion. BREEAM method

which was most favoured and most commonly used by researchers has been designed as a tool for experts who are able to assess with the help of 10 groups of criteria, however application of this method does not guarantee result objectivity due to possibly different terms and conditions of expert assessment.

3) An innovative building sustainability evaluation methodology based on the multi-criteria Copras evaluation method has been presented. Application of this method will allow an objective evaluation of building sustainability behavior while using 11 groups of criteria. An advanced modification of the suggested method will allow more accurate estimates following the presented criteria groups, therefore the result will be more objective in comparison to other currently used methods.

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