



EVALUATION OF CONSTRUCTION SUSTAINABILITY BY MULTIPLE CRITERIA METHODS

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Abstract. Sustainable construction is a relevant subject in contemporary world because it is one of approaches achieving sustainability in all the spheres of society development. The authors reveal difficulties which emerge in creating the indicator system for sustainability evaluation, searching for information concerning indicators and in making mathematical calculations. After thorough analysis of research papers, specific databases and other information sources an algorithm for indicator system creation was suggested. The set of construction sustainability indicators for a particular country was built, the values of indicators were defined and then several decision-making methods were applied. According to a general index of construction sustainability, a conclusion was drawn about construction state in the context of sustainable development.

Keywords: sustainability, sustainable construction, sustainable development, evaluation, indicator system, decision-making methods.

1. Introduction

Construction as any production activity consumes energy, physical and human resources and also has an impact on the environment. At the same time external factors, as rising competition, running out resources, tightening of environmental protection standards, push to look for innovations in the construction sector. Sustainable construction approach exists in the world for more than ten years. The principles of this approach should ensure sustainable development of the construction sector, however, due to definition versatility of sustainable construction there appear many problems when applying it in a particular country. The problem is that the sustainable construction conception can vary according to the country's size, level of economic development as well as social, cultural and other factors. Consequently, in order to assess the efficiency of sustainable construction principles applied, one should determine what sustainable construction means for a particular country. This is the problem of creation of an indicator system characterizing construction and forthcoming calculations. Consequently, the aims of this work are: 1) formulation of general requirements for sustainability indicators;

2) creation of a construction sustainability indicator system and establishment of values for these indicators; 3) calculation of the index of sustainability level by using multiple criteria decision-making methods; 4) drawing conclusions on the condition of construction in the context of sustainable development.

2. Sustainability and construction. Sustainable construction

Sustainability is seen as a way for the construction industry in achieving sustainable development [1]. Most authors give Kibert definition for sustainable construction: “the creation and responsible management of a healthy built environment based on resource efficient and ecological principles” [2].

Since the First International Conference on Sustainable Construction there were many attempts to analyse different sustainable construction problems.

O. Ozgener [3] recognizes that energy conservation, pollution prevention, resource efficiency, system integration and life cycle costing are very important factors for

sustainable construction. The authors' work was to ensure power supply by using wind power to comply with the green building approach.

Investigations (M. J. Gonzalez and J. G. Navarro) [4] show the possibility of reducing CO₂ emissions up to 30 % in the construction phase through a careful selection of materials of a low environmental impact. The purpose of a recent study is to quantify the total amount of CO₂ emissions saved by the method presented in a particular phase of material selection within the life cycle of a building. This material selection as well as the bioclimatic characteristics must be defined from an early design project phase.

M. Zimmermann et al [5] performed benchmarks for sustainable construction to define requirements for buildings and structures in contributing to the achievement of a sustainable society. The permissible impact of buildings, in terms of energy demand and pollutant loads during construction, maintenance and operation, is determined. The authors' analysis focuses on identifying the permissible levels of loads based on the specific energy consumption per m² and year for heating, hot water, electricity and construction.

D. van Gemert et al [6] outlined the 11th International ICPIC Congress which took place in Berlin on 2–4 June 2004. New trends and evolutions were presented and discussed during the Congress. The authors state that search for durable and sustainable construction materials inspires developments in the sphere of cement concrete as well as in that of concrete-polymer composites. A better knowledge of material behaviour, especially in the field of admixtures as well as a better understanding of curing processes allowed the development of highly performing mineral or modified mineral concretes, mortars and grouts. CPC-science becomes an invaluable element in the development of sustainable construction materials. ICPIC brings together practitioners and researchers, dealing with concrete-polymer composites in all industrial fields, but with emphasis on construction industry.

S. Pushkar et al [7] established a simple but reliable methodology for the building design stage that would yield environmentally optimal buildings. A three-step methodology is proposed: (1) design variable grouping – four distinct groups were recognized according to their stage of major influence (production and construction, operational energy, maintenance to demolition, and an Integrated Group relevant to several life cycle stages), (2) generating the within group optimization methodology, and (3) integration.

In line with the promotion of sustainable construction in the past decade, construction professionals have made contributing efforts in protecting the environment in implementing construction activities (L.-Y. Shen et al) [8]. Whilst such efforts will be made continuously, it is important that the level of the environmental performance in implementing construction activities can be properly measured and com-

municated to the public and project participants. The authors present a scoring method for measuring the environmental performance committed by a contractor through calculating the contractor's environmental performance score (EPS). The level of EPS serves as a simple indicator for measuring and communicating the level of a contractor's environmental performance. The procedure for calculating EPS is formulated as an information technology IT-supported program.

J. de Brito et al [9] studied issues of construction waste re-use. According to the authors, to reduce the volume of ceramic waste from the construction industry, it is possible, among other applications, to use it as aggregates in the production of non-structural concrete artefacts. The study shows that there is a potential for the use of these ceramic aggregates in elements in which the primary requirement is not compressive strength but tensile strength and abrasion resistance, such as for concrete pavement slabs.

Despite a rapid increase in the building industry's contribution to resource depletion, waste generation and energy consumption, the creation of built environment remains vital to a country's economic development (R. Emmanuel) [10]. This makes the building industry a prime candidate for sustainable development. Tools that help to estimate the environmental suitability of building products can advance the cause of sustainable development. The author estimates the environmental suitability of the most commonly used wall materials. An "Environmental Suitability Index" is developed based on three parameters: embodied energy, life-cycle costs and re-usability.

In view of the mounting cost of rehabilitating deteriorating infrastructure, further compounded by intensified environmental concerns, it is now obvious that the evolution and application of advanced composite structural materials to complement conventional construction materials is a necessity for sustainable construction (W. O. Oyawale et al) [11]. This study seeks alternative fill materials (polymerbased) to the much-limited cement concrete used in concrete-filled steel tubular structures.

It is acknowledged that construction activity has major impacts on the environment (G. Ofori) [12]. Moreover, the construction process is usually fragmented and involves several parties with different objectives. Thus, often none of them normally assumes direct responsibility for protecting the environment. The concept of the supply chain management (SCM) is now commonly applied in business for the mutual benefit of enterprises in the supply chain (from the organization extracting the basic raw material to the final customer). The basic principle of SCM is "integration". The author considers the potential of applying SCM to integrate the construction process in Singapore, and thereby, address its pressing problems including its poor environmental performance. It is found that SCM can help to green the construction supply chain.

Energy-efficient, economical and durable building materials are essential for sustainable construction practices (B. V. Venkatarama Reddy and S. S. Lokras) [13]. The authors deal with production and properties of energy-efficient steam-cured stabilized soil blocks used for masonry construction. The research revealed that energy-efficient steam cured soil blocks (consuming less thermal energy by 35 % compared to burnt clay bricks) having a high compressive strength could be easily produced in a decentralized manner.

Sh. L. Huang and W. L. Hsu [14] attempt to incorporate resource and material flow analysis to investigate Taipei area’s urban sustainability due to urban construction. In the past decade material flows (sand and gravel, cement, asphalt and construction waste) for constructing major urban engineering projects, such as roads, bridges, MRT, flood prevention projects, storm drainage and sewerage pipes, and buildings are analysed for Taipei metropolis. In order to evaluate the contributory value of material flows to the ecological economic system, energy evaluation is incorporated in this research. A framework of indicators, including the categories, such as (1) intensity of resource consumption; (2) inflow/outflow ratio; (3) urban livability; (4) efficiency of urban metabolism; and (5) energy evaluation of urban metabolism, is developed for measuring the effect of urban construction on Taipei’s sustainability.

3. Establishment of indicator system for evaluation of sustainable construction

Review of research works on sustainable construction shows that most researchers analyse particular problems concerning sustainable construction: efficient use of energy and other resources, prevention of pollution, development of new materials, etc. However, it should be recognized that the term “sustainability” is complex, global and by nature covers three components: social, economic and environmental factors. There is lack of overall evaluation by these three aspects. What could characterize sustainable construction on a national, country’s scale? There is need of a global system of social, economic and environmental

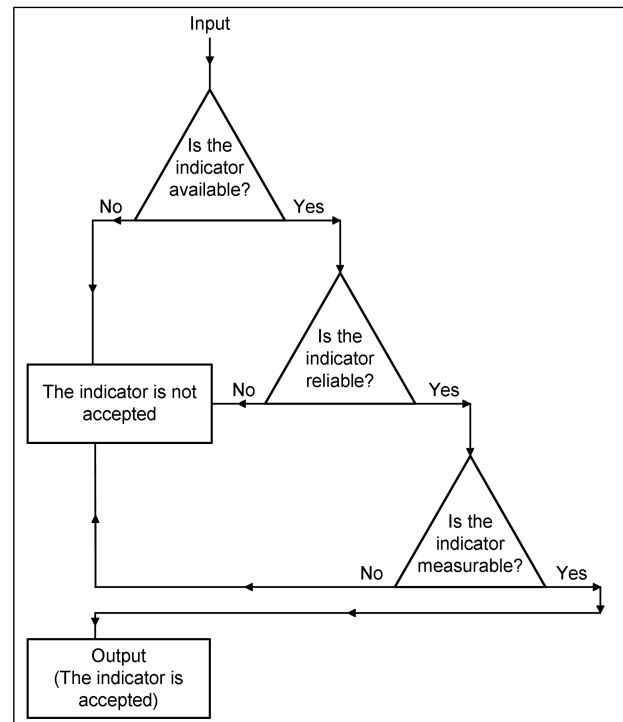


Fig 1. Indicator selection procedures

indicators operating in the construction sector. Then there arise three questions: 1) what requirements should be set for indicators? 2) there is no general indicator system developed in the world, so what it should look like? 3) there is no special information that is documented concerning only construction sustainability indicators, so how could the values of indicators be found out then?

There could be different requirements for indicators. Summarizing the practice used, the following procedures (algorithm) for indicator selection is suggested (Fig 1).

According to official statistics [15], the indicator system that reflects country’s construction sustainability is suggested. The system consists of six indicators altogether. The first and second indicators are social, the third and fourth ones – economic, the fifth and sixth ones – environmental (Table 1).

Table 1. Indicator system for construction sustainability evaluation

Indicators	Units	*	Years compared				
			2000	2001	2002	2003	2004
1. Dwellings completed	Thousand m ²	+	498,8	376,0	451,5	482,6	699,1
2. Public buildings completed	Thousand m ²	+	46,8	48,6	56,5	94,3	52,6
3. Labour productivity in construction	GVA per actual hour worked, LTL	+	24,7	23,4	29,1	32,5	31,1
4. Gross value added and gross domestic product in construction	At constant prices, LTL million	+	2407,0	2587,5	2918,2	3586,4	3772,7
5. Final energy consumption in construction	Thousand tonnes of oil equivalent (TOE)	-	40,7	37,6	41,4	45,6	46,9
6. Energy intensity in construction	Tonne of oil equivalent (TOE)/LTL million GDP	-	15,0	12,9	12,6	11,3	11,0

4. Assessment of construction sustainability

4.1. Technique for order preference by similarity to ideal solution (TOPSIS)

Technique for order preference by similarity to an ideal solution based upon the concept that a chosen alternative should have the shortest distance from an ideal solution and the farthest one from a negative-ideal solution (Hwang and Yoon) [16].

Step 1. Construct the normalized decision matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}, \quad (1)$$

where r_{ij} – an element of the normalized decision matrix.

Step 2. Determine ideal and negative-ideal solutions:

$$A^- = \left\{ \left(\min_j v_{ij} \mid i \in I \right), \left(\max_j v_{ij} \mid i \in I' \right), j = 1, 2, 3, \dots, m \right\} = \{v_1^-, v_2^-, \dots, v_n^-\}. \quad (2)$$

$$A^+ = \left\{ \left(\max_j v_{ij} \mid i \in I \right), \left(\min_j v_{ij} \mid i \in I' \right), j = 1, 2, 3, \dots, m \right\} = \{v_1^+, v_2^+, \dots, v_n^+\}. \quad (3)$$

Step 3. Calculate the separation measure:

$$S_i^+ = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^+)^2}, \quad j = 1, 2, 3, \dots, m; \quad (4)$$

$$S_i^- = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^-)^2}, \quad j = 1, 2, 3, \dots, m. \quad (5)$$

Step 4. Calculate relative closeness to an ideal solution:

$$C_j^+ = \frac{S_j^-}{S_j^+ + S_j^-}. \quad (6)$$

The computer program LEVI 3.0 [17–20] developed at Vilnius Gediminas Technical University for the data presented in Table 1 was applied, and calculations according to formulas (1–6) were performed. The outputs of this program are presented in Figs 2 (initial data) and 3 (calculation results).

4.2. Simple additive weighting (SAW)

The simple additive weighting method (SAW) is probably the best known and very widely used. The model is used to aggregate the scores into one score based on the criteria weights (Hwang and Yoon [16]; Zavadskas and Kaklauskas [21]; Balcomb and Curtner [22]; Triantaphyllou [23]).

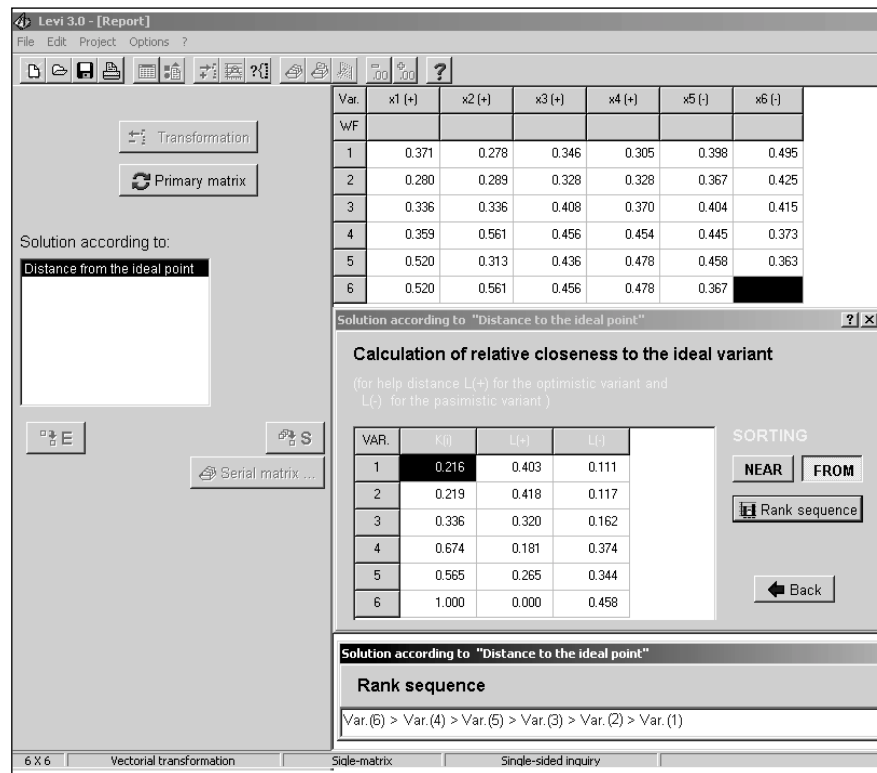


Fig 2. Solution results

At first, the scores are normalized (converted) by the formulas

$$x_{ij} = \frac{a_{ij}}{a_j^{\max}}; \quad (7)$$

$$x_{ij} = \frac{a_j^{\min}}{a_{ij}}, \quad (8)$$

where a_{ij} is the score for the criterion. When criteria are maximized, formula (1) has to be used, and formula (2) has to be used when criteria are minimized.

Then the scores are aggregated into one score:

$$S_{SAW} = \max_j \sum_{i=1}^m x_{ij} \times w_i, \quad j = 1, \dots, n, \quad (9)$$

where S_{SAW} is the total score, n is the number of criteria, w_i is the weight of the criterion, and x_{ij} is the normalized score for the criterion.

After calculations according to formulas (7–9) the following results were obtained: $S_{2000} = 0,711$; $S_{2001} = 0,719$; $S_{2002} = 0,783$; $S_{2003} = 0,906$; $S_{2004} = 0,886$.

5. Conclusions

1. The research reveals that there are many attempts to analyse different problems of sustainable construction (SC), but it shows lack of SC assessment in the whole industry or country.

2. An indicator system for construction sustainability evaluation in Lithuania is developed.

3. Since assessment of sustainable construction is a complex issue, multiple criteria methods are applied: technique for order preference by similarity to ideal solution (TOPSIS) and simple additive weighting (SAW).

4. Both methods show that construction industry moves towards sustainability in Lithuania (Fig 3).

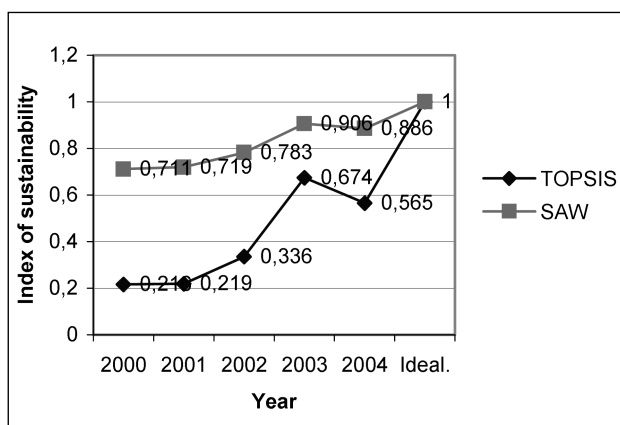


Fig 3. Overall sustainability index calculated by TOPSIS and SAW methods

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STATYBOS DARNOS VERTINIMAS DAUGIAKRITERINIAIS METODAIS

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Santrauka

Darnioji statyba – aktuali tema šiuolaikiniame pasaulyje, nes tai yra vienas būdų, siekiant darnaus vystymosi visose visuomenės raidos sferose. Autoriai atskleidžia sunkumus, kurie atsiranda, kuriant statybos darnos įvertinimo rodiklių sistemą, renkant informaciją apie rodiklius ir atliekant matematinius skaičiavimus. Atlikus išsamią mokslinių šaltinių analizę, pasiūlyta statybos darnos rodiklių sistemos sudarymo loginė schema. Sudaryta konkrečios šalies statybos darnos rodiklių sistema ir nustatytos rodiklių reikšmės, pritaikyti keli sprendimų priėmimo metodai. Pagal kelerių metų statybos darnos kompleksinio rodiklio reikšmės daroma išvada apie statybos būklę darnaus vystymosi kontekste.

Reikšminiai žodžiai: darnioji statyba, darnus vystymasis, įvertinimas, rodiklių sistema, sprendimų priėmimo metodai.

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