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Application of multi-criteria evaluation methods to create urban development opportunities within the concept of sustainable architecture of buildings and urban areas

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Abstract. The advancement of urban development has made it possible to improve the quality of infrastructure and the organization of urban territories, affecting cities' competitiveness and investment attractiveness. The study aims to apply multi-criteria evaluation methods to create urban development opportunities in the sustainable architecture of buildings and urban areas. The primary data collection methods include document analysis and an expert survey. Through document analysis, the authors identify the basic methods of evaluating buildings and architectural objects to establish compliance with the requirements of sustainable architecture. The expert survey results highlight the most dynamically developing and globally recognized methods: LEED and BREEAM. Further analysis sheds light on the specific features of criteria-based evaluation of buildings under LEED and BREEAM certification, compares the lists of building evaluation criteria in BREEAM and LEED, and considers the practical implementation of LEED and BREEAM building certification while highlighting and describing architectural objects. The authors conclude that the standards defined in the BREEAM and LEED multi-criteria methods exhaustively conform to the principles of sustainable architecture, encompassing environmental, economic, and social conditions. BREEAM and LEED can be applied to new and modernized residential and public buildings.
Keywords: sustainable architecture, architectural design, building certification method, LEED, BREEAM, urban development

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1. INTRODUCTION

Research problem. Contemporary urban development is the economic foundation for developing the real estate market and urban territories, shaping the competitive environment of the real estate market and ensuring efficient management of real estate objects [1]. Development activity entails initiating and realizing an idea at the stage of the conception of a future construction project, distinguishing the developer among other participants in the development of the real estate market. The work of developers has a narrower goal, always commercial, connected with increasing the prices of buildings, their liquidity, and the efficiency of use of the entire developed area. Modern developers, especially in large cities, pay great attention to architecture [2]. Architecture is a vital element in the development of the environment to preserve natural balance and ensure the longevity of basic natural processes [3, 4]. In times of environmental threats, architecture is called upon to guarantee the satisfaction of the basic needs of individuals and communities now and in the future [5, 6]. Integrating architectural activities into the design process according to the principles of sustainable development can contribute to significant changes [7, 8]. On the one hand, this approach is associated with reducing energy, water, material, and raw material consumption and decreasing the number of repairs and operating costs for the facility [9]. On the other hand, sustainable architecture needs to satisfy human needs in physical and mental comfort, safety, identity, and aesthetics [10]. It needs to provide a sense of proximity, isolation, bioclimatic comfort, safety, hygiene, and mental and physical tranquility [11].

Architecture designed and materialized according to the principles of sustainable development brings significant benefits:

- for the environment by contributing to the reduction of natural resource use and curbing its degradation [12-14],
- for human health and safety by promoting human comfort and quality of life [15],
- for economic efficiency, facilitating savings in the building operation and the design system [16].

Evaluating architecture from the perspective of sustainable development involves establishing criteria and standards to serve as the foundation for evaluating architectural solutions and deciding whether an object or complex of objects conforms to the specific conditions of sustainable development of human habitat [17].

There are multi-criteria methods for evaluating buildings that, if conditions are met, issue certificates confirming the use of solutions promoting sustainable development [18]. Based on these multi-criteria building evaluation methods, programs have been developed to codify the certification procedures [19]. Joining the program and aligning architecture with sustainable development principles is voluntary and demonstrates a serious approach of the investor and user to the common good which is the human habitat [20].

This testifies to the relevance of analyzing the methods for certifying compliance with the requirements of sustainable architecture.

O. Süzer's [21] analysis of existing methods for testing the quality of buildings illuminates the divergence of the objectives of methods depending on the set of criteria. Methods for assessing the anthropogenic environment are evolving along several main lines: at the urban level, i.e., environmental, social, and aesthetic, and at the construction (architectural) level, which includes the following directions: environmental and energy (broadest development) [22], comfort and effectiveness (the trend of usefulness) [23], aesthetic qualities [24], the quality of management [25], building life cycle costs [26], and the orientation of modernization [27, 28].

J. Jeong et al. [29] conclude that there is no universal method for studying building sustainability. However, the numerous quality assessment methods allow one to expand one’s knowledge about buildings. These methods continuously improve people's lives in a sustainable environment.

The analyzed methods point to several primary criteria, which focus on:

- energy efficiency of the architectural structure and the use of renewable energy sources [30],
- the effectiveness of water and sewerage management [31],
- effectiveness in the use of materials and raw materials and their pro-ecological parameters [32],
- pro-ecological land use [33, 34],
- local preferences and pro-ecological innovations [35].

These criteria stem from existing environmental and economic conditions and affect them.

The analyzed methods include criteria focusing on the quality and convenience of use. These criteria are derived from social conditions, although they do not fully encompass them.

To improve the effectiveness of their work, the developer, relying on the analysis of multi-criteria building evaluation and certification programs, needs to consider recommendations for the design, construction, and use of buildings in line with sustainable development principles:

1. Building demolition and remodeling should only be undertaken when it is economically or practically infeasible to utilize, adapt, or expand an existing structure.
2. Transportation during demolition, renovation, and construction needs to be reduced, and all processes need to be strictly controlled to reduce noise, dust, vibration, pollution, and waste.
3. The land should be utilized to its full potential, for example, by studying its history, purpose, microclimate, prevailing winds, weather cycles, sunlight orientation, accessibility to public transportation, and the architectural form of surrounding buildings.
4. The building should be designed to minimize its cost to the user and its environmental impact during operation, making it easy to maintain, energy and water efficient, and safe for human health by reducing harmful emissions.
5. Wherever possible, construction techniques should be appropriate to the locality, considering local traditions in materials and design.
6. It is essential to ensure functionality and comfort, making the building safe, flexible, adaptable to future needs, and able to facilitate and encourage communication between users.
7. Materials from non-renewable sources or those that cannot be reused or recycled should be avoided. This applies particularly to structures with a short service life.

The study aims to conduct a comparative analysis of methods for certifying buildings' compliance with sustainable architecture requirements.

2. MATERIALS AND METHODS

The methodological basis consisted of a review of scientific literature on the research problem, the study and analysis of architectural projects and their realization from the standpoint of sustainable development, a comparison of existing building certification methods, and an expert survey [36] to substantiate the choice of the most dynamically developing and globally significant methods of assessing architectural objects from a sustainable development perspective.

The study was conducted in January-March 2024 by a group of researchers.

At the first stage, information sources warranted by the research goal were selected from among monographs and articles indexed by Scopus, Web of Science, CyberLeninka, and eLibrary.Ru. The source base was limited by the requirement of free access to the materials.

At the second stage, to increase the validity of findings, the reliability of the source base was analyzed using an email survey of 40 experts in building and structure examination. The eligibility criterion for expert selection was at least three articles on our research topic indexed by Scopus, Web of Science, or eLibrary.Ru or participation in the building (structure) certification.

The experts were contacted by email to ask them to evaluate the reliability of the selected materials. A 10-item survey was compiled for the experts to assess the documents chosen for analysis. The experts conducted their assessment using the Harrington scale [37]. Two questions were open-ended, allowing the experts to leave suggestions to increase/decrease the number of important sources or comment on their answers. All respondents were given the same number of calendar days to complete the survey, ensuring equal conditions. The results limited the source base and assessed its reliability according to the Harrington scale (0.72 points – a high score). The survey results are summarized in Fig. 1.

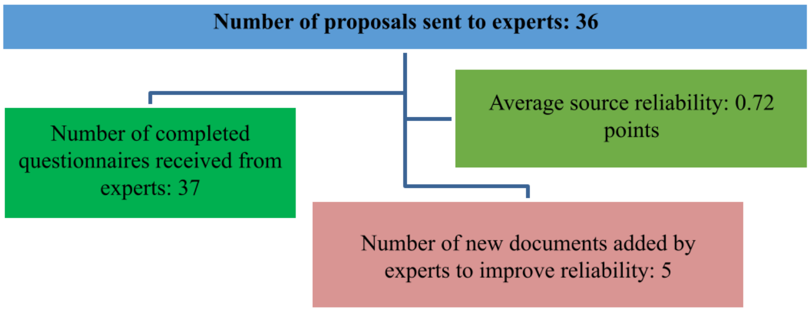

Fig. 1. Summarized data with the results of the expert survey assessing the reliability of the selected documents.

At the third stage, we analyzed existing methods of codification and definition of standards for building evaluation. This analysis included three main stages: identifying the object of study, in our case – the method of evaluating buildings and architectural objects; collecting materials about the selected method through desk research; and systematizing the data. The methods selected in our study included LEED, BREEAM, Green Building (EU), Green Building Challenge (GBC), DGNB (German Sustainable Building Council), BEPAC, and HQE.

At the fourth stage, the comparative analysis method was used to analyze the assessment methodologies that ranked 1st and 2nd in the third stage (LEED and BREEAM) to determine their similarities and differences. To identify them, we selected a set of architectural objects awarded LEED (objects in the USA and Europe: Adobe Towers office buildings, the CSOB Financial Group office building Visegrad Victoria, the Eiffel Square office complex, the K&H Bank TriGranit office complex, and the Borg Warner Corporation building) and BREEAM certificates (four objects in Europe: the Rivergreen office center, Hermitage Plaza Centrum, Quadrum business park, and Trinity Park III office and conference center).

The fifth stage consisted of summarizing the collected information and processing the results using descriptive statistics, ranking, and weighting in Excel.

3. RESULTS AND DISCUSSION

3.1. Analysis of the Methods of Codification and Definition of Building Evaluation Standards

A list of the most prominent methods for evaluating architectural objects from the perspective of sustainable development is presented in Table 1.

Table 1. Selected methods for evaluating buildings and architectural objects.

No.	Evaluation method	Goal	Creators of the method/program	Rank	Weight
1	LEED	Evaluation from the standpoint of sustainable development	US Green Building Council (USGBC) (USA)	1	0.34
2	BREEAM	Evaluation from the standpoint of sustainable development	Building Research Establishment (BRE) (Great Britain)	2	0.28
3	Green Building (EU)	Energy efficiency, sustainable development	National Contact Point (EU)	3	0.13
4	Green Building Challenge (GBC)	Evaluation from the standpoint of sustainable development	Proposals developed by an international team	4	0.10

Continuation of Table 1

5	DGNB (German Sustainable Building Council)	Evaluation from the standpoint of sustainable development	DGNB, Federal Ministry of Transport, Building, and Urban Affairs	5	0.07
6	BEPAC	Evaluation from the standpoint of sustainable development	Developed based on the BREEAM program (Canada)	6	0.05
7	HQE	Evaluation from the standpoint of sustainable development	HQA Association (France)	7	0.03

According to our experts, LEED and BREEAM are the most dynamically developing and globally recognized methods. The Green Building certification program has a European ranking and the DGNB method is of interest to specialists, but the certification process is in its early stages. Some methods, including HQE and BEPAC, have not reached world significance.

Our further analysis focused on LEED and BREEAM.

3.2. Comparative Analysis Based on LEED and BREEAM

3.2.1. LEED

The LEED (Leadership in Energy and Environmental Design) standards have been modernized and updated repeatedly. They have been adapted to evaluate buildings with different functions and construction conditions, with five main criteria until 2002 and seven since 2009.

LEED envisages that the evaluation and qualification of buildings can be conducted in two phases:

- at the design stage,
- upon completion of the investment.

The stepwise assessment allows for the efficient organization of certificate issuance and deficiency correction as early as the initial design stage.

The method developed by the US Green Building Council prescribes seven key evaluation criteria. For each criterion (Table 2) you can get a certain number of points (depending on the quality achieved) (Fig 2).

Table 2. Evaluation criteria.

No.	Criterion	Essence
1	Integration of the object with the environment	Prevents environmental degradation during the construction and operation of a sustainable architectural object
2	Water and sewerage management effectiveness	Reduces water resources use by at least 20%
3	Energy consumption	Limits energy consumption
4	Raw materials and supplies	Establishes the proper management of raw materials and supplies during the construction and operation of the facility
5	Eco-friendliness and ease of use	Influences the attainment of the minimum expected indoor air quality
6	Innovation and the quality of design solutions	Evaluates high-quality design solutions that go beyond codified program procedures
7	Regional priorities	Evaluates the use of regional priorities recommended by local authorities in design and realization decisions

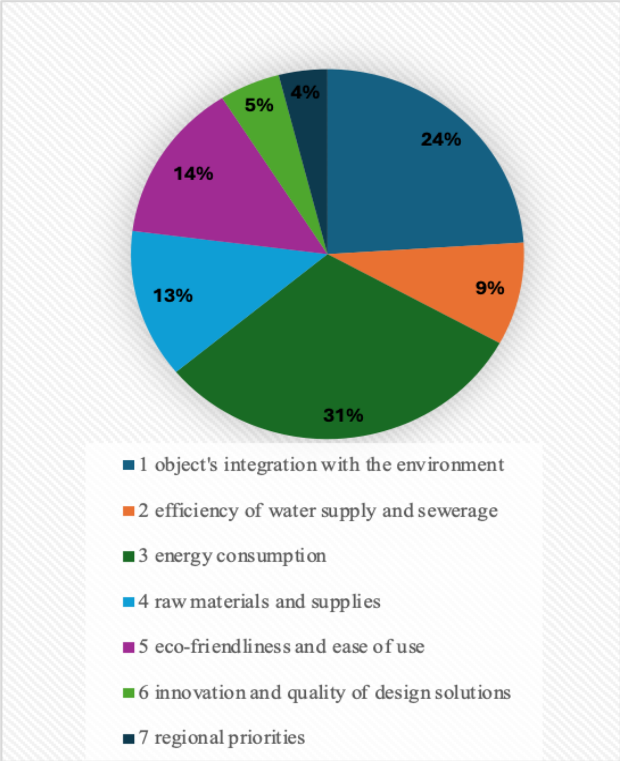

Fig. 2. Criterion evaluation of buildings using the LEED method.

The greatest score range belongs to energy consumption, accounting for 31% of the total score. The second important direction is integrating the object with the environment with 24%. Thus, the LEED standards emphasize the importance of energy consumption, the quality of the atmosphere, and the object's integration with the environment for the operation of sustainable architecture.

The number of points awarded depends on the quality results, and the level of certification is determined by the sum of the points received. The number of points decides the standard of ecological architecture and the certification level (Fig 3).

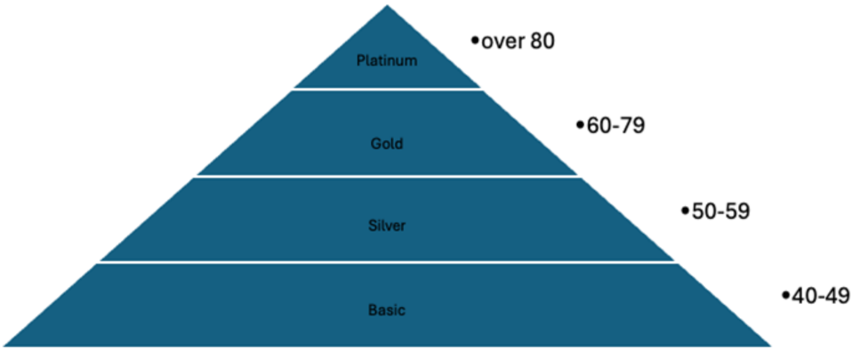

Fig 3. Number of points.

LEED certification is mainly valid in the USA, although increasing interest is observed in Europe, the Middle East, and Africa. As a program that comprehensively addresses sustainability issues, LEED is gaining interest and credibility among investors, developers, and architects.

The list of analyzed and selected LEED-certified architectural objects is presented in Table 4.

Table 4. List of analyzed architectural objects awarded with LEED certificates.

No.	Object	Location	Certificate, year of issue
1	Adobe Towers office buildings	San Jose (USA)	LEED 2006
2	CSOB Financial Group office building Visegrad Victoria	Prague (Czech Republic)	LEED 2007
3	Eiffel Square office complex	Budapest (Hungary)	LEED 2010
4	K&H Bank TriGranit office complex	Budapest (Hungary)	LEED 2010
5	Borg Warner Corporation building	Rzeszów (Poland)	LEED 2010

Let us consider these objects in more detail.

In 2006, a building in ADOBE Corporation's complex, West Tower115 in San Jose, California, became the world's first building to receive LEED Platinum certification. Two more ADOBE towers received platinum certification in 2011.

The LEED program is gaining popularity among European investors, developers, and architects, joined by numerous projects in Central and Eastern Europe. The leading countries are the Czech Republic, Hungary, and Poland.

The headquarters of CSOB Financial Group in Prague was handed over to the investor in 2007. The eight-story Visegrad Victoria complex was the first in the Czech Republic to receive the prestigious LEED certificate. The Eiffel Square office complex, in the center of Budapest, was commissioned in 2009 and was LEED-certified the following year, as was the K&H-TriGranit banking complex, which opened its doors in 2010.

The building complex of the American concern Borg Warner, which manufactures turbochargers and pneumatic system components and supply and emission reduction systems for passenger and commercial vehicles, was built in the science and technology park in Rzeszów (Poland) in 2009 according to LEED standards. The construction of external walls and the roof complies with the highest insulation standards. The facility’s construction, materials, and technologies comply with environmental conditions. The complex uses automatic energy management, which affects its energy balance.

Buildings designed according to LEED standards enjoy great recognition and credibility among professionals, users, and residents.

3.2.2. BREEAM

The BREEAM (Building Research Establishment Environmental Assessment Methodology) standards were developed in the UK in 1990-1993 and supplemented in 1998. The standards have been improved practically since 2002 and are covering buildings for different purposes. The latest revision of the standards took place in 2009.

The provisions of the method establish a two-stage evaluation procedure for the 1) design and 2) implementation and post-implementation phases.

The evaluation proceeds from three levels of impact on the environment: global, local, and internal.

BREEAM is suited for evaluating a variety of buildings. Outside of the UK, it is tested on sustainable architecture objects whose investors have joined the certification program in Europe and other continents.

BREEAM specifies criteria for the performance of an architectural object or set of objects in relation to the environment from a sustainable development perspective, including eight main evaluation criteria (Table 5) and one additional criterion with a maximum percentage of points that can be obtained (Fig 4).

Table 5. Evaluation criteria.

No.	Criterion	Essence
1	Management	Examines and assesses conditions related to the environmental impact of construction, as well as the conditions and organization of the object's construction process in terms of sustainable development
2	Health and quality of life	Analyzes and evaluates the quality of daylight, quality of view (window space) from individual workstations, sunlight control system, quality of lighting and its control system, natural ventilation capability, indoor air quality, thermal comfort parameters, the occurrence of contaminants, and microbiological and acoustic quality
3	Energy	Investigates and evaluates the conditions based on the building's energy performance certificate associated with the reduction of CO2 emissions and the use of meters for major energy consumers and major high-energy appliances, along with the energy efficiency of the appliances used
4	Transport	Considers and evaluates accessibility, i.e., proximity and frequency of public transportation, proximity of retail and service facilities, alternative transportation options, pedestrian and bicyclist safety, the use of parking facilities, and the developed traffic patterns
5	Water	Studies and evaluates water consumption, the use of metering devices, fault detection systems, the use of plant watering and vehicle washing, sewer management, and the use of in-house water treatment facilities
6	Materials	Examines and evaluates the environmental characteristics of the materials used, their source of origin, the range of recycled materials, and the quality of insulation and its resistance to degradation
7	Land use and ecology	Studies and assesses the environmental value of the site, mitigation of negative environmental impact and long-term impact on biodiversity, and the issue of site reuse and recultivation
8	Pollution and waste	Analyzes and evaluates conditions related to the use of refrigerants and leakage protection systems, rainwater quality, the reduction of light pollution, environmental noise issues, and the utilized floor finishing methods; the conditions related to the sorting and recycling of construction waste, the use of storage and sorting systems during the building's use
9	Innovation	Examines and evaluates the innovativeness of pro-environmental solutions that contribute to sustainable development

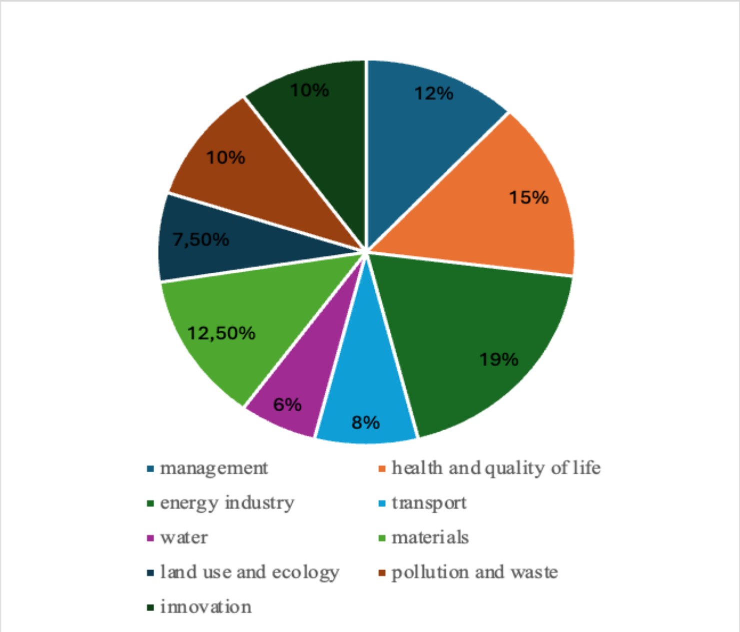

Fig. 4. Criterion evaluation of buildings using the BREEAM method.

The sum of initial assessment scores in the design phase and later in the implementation phase gives a specific result, and thus the level of the certificate issued is determined as follows (Table 6).

Table 6. Certificate levels.

Certificate level	% of maximum score
Pass	No less than 30%
Good	No less than 45%
Very Good	No less than 55%
Excellent	No less than 70%
Outstanding	Above 85%

Approximately 20% of newly built office buildings in the UK meet BREEAM standards, mainly due to the requirements of investors and companies renting these premises.

The list of analyzed and selected architectural objects marked with BREEAM certificates is presented in Table 7.

Table 7. List of analyzed architectural objects awarded with BREEAM certificates.

No.	Object	Location	Certificate, year of issue
1	Rivergreen office center 	Durham (UK)	BREEAM 2006
2	Hermitage Plaza Centrum 	Courbevoie (France)	BREEAM 2009

Continuation of Table 7

3	Quadrum business park 	Budapest (Hungary)	BREEAM 2009
4	Trinity Park III office and conference center 	Warsaw (Poland	BREEAM 2010

Let us examine them in more detail.

The Rivergreen office center erected in Durham (UK) opened its doors in 2006. The buildings use renewable energy sources, solar collectors, and heat pumps. Indoor temperature is controlled and regulated according to external conditions, which reduces energy demand. The innovative solution of floating ceilings has an extremely positive effect on the acoustic conditions of the office space. The complex utilizes several solutions in line with the principles of sustainable development. Recycled materials are widely used in construction. Sanitary facilities employ water reuse. Only recycled water from precipitation is used for irrigation of greenery. More than 60% of the energy required for water heating comes from solar collectors installed on the rooftops. The office complex has been awarded the highest BREEAM certificate.

The Hermitage Plaza office, hotel, and residential complex was erected in the Courbevoie suburb of Paris. In addition to the construction of the buildings, the environmental project also includes the development of coastal areas where cafes and restaurants were built. The buildings surround a public square, the center of Courbevoie's social life. Glass panels with excellent thermal parameters covering the facades of buildings reflect light, making their appearance change depending on the time of day and weather. The angled positioning of the panels creates shadows on the facades and prevents the buildings from heating up too much. The environmental solutions used in the project have received the highest BREEAM rating.

The Rivergreen Center in Durham and the mixed-use development in Courbevoie illustrate the scale of the opportunities for implementing architecture according to BREEAM standards. Both buildings have achieved the highest level of certification at the implementation, use, and design stages, despite their different approaches to architecture, functions, scope, and scale.

Quadrum business park was built in Budapest in 2009, an example of a new generation of projects combining modern architecture with solutions that reduce energy consumption and limit the facility's negative environmental impact. Quadrum business park fulfills the standards specified in the program. It is the first building in Central Europe to receive BREEAM certification.

Trinity Park III in Warsaw comprises three BREEAM-compliant office and conference complexes. The center features energy-saving air conditioning, ventilation, heating, and lighting systems and energy-saving elevators. An extensive automatic control system was installed in the buildings. The materials were carefully selected from an environmental point of view. The collection and utilization of rainwater increases the economic efficiency of the buildings. A specialized analysis prefaced the choice of the facade curtain wall system.

3.2.3. Comparative Analysis of Building Certification Methods

Table 8 presents the comparative characteristics of the BREEAM and LEED building survey and assessment criteria together with their respective scores expressed in percentages.

Table 8. Comparative list of BREEAM and LEED building evaluation criteria.

Evaluation criteria employed in the method				Commonality of criteria	Conditions		
BREEAM	Points, %	LEED	Points, %		Environmental	Economic	Social
Energy	19	Energy consumption (energy and atmosphere)	31	Energy efficiency	X	X	-
Pollution and waste	10						
Health and quality of life	15	Eco-friendliness and ease of use	15	Comfort of use	-	-	X
Water	6	Water and sewerage management effectiveness	10	Water and sewerage management effectiveness	X	X	-
Materials	12,5	Raw materials and supplies	14	Effectiveness of the use of materials and raw materials	X	X	-
Land use and ecology	10	Integration of the object with the environment	26	Pro-ecological land use	X	X	-
Management	12						
Transport	8						
Innovation	10	Innovation and the quality of design solutions	6	Local preferences and pro-ecological innovations in the project	X	X	
		Regional priorities	4				

Table 8 indicates that the scope of the codified building evaluation standards in BREEAM and LEED includes comparable (similar) problem areas and point values in their evaluation, creating a common field of criteria. The criteria thus include energy efficiency, usability, water and sewerage management efficiency, material and raw material efficiency, pro-environmental use of the area, local preferences, and pro-environmental innovations of the project.

The findings led us to several conclusions on applying multi-criteria methods to advance urban development within the framework of sustainable architecture of buildings and urban areas.

First, urban development in the framework of sustainable architecture has entered the stage of widespread implementation [38]. Multi-criteria building evaluation methods codifying design and implementation standards continue to develop. Projects are designed in compliance with established standards, implemented, and awarded with certificates, which are becoming increasingly prestigious [39]. According to Birgisdottir and Hansen [40], codified standards, although not fully reflecting the complex process of sustainable design in architecture, are worthwhile and contribute to the widespread adoption of sustainable development.

Second, sustainable architecture standards should be understood as value criteria for designing, implementing, and using an architectural object in sustainable development. The list of standards and the systematization of principles and rules for evaluating the design of an architectural object and its implementation and use are defined as codified standards of sustainable architecture [22].

Third, there is no consensus among researchers about the weight (importance) of the codified sustainable architecture standards compared to each other. Researchers refer to sustainable architecture as a method of protecting natural resources using renewable energy [41]. The design process should address material selection, the organization of the construction and transportation processes [42], operating costs, adaptability, recyclability, etc., along with the specific impact of new materials and technologies on form [43]. Amado et al. [44] consider the main aspect of sustainable architecture to be the choice of materials and methods of their use and energy self-sufficiency.

Fourth, the projects and building performance experience we analyzed show that the core sustainability criteria are met in the design process to varying degrees depending on the assessment method. The building assessment criteria specified in BREEAM and LEED broadly cover sustainability issues. Jeong et al. [29] point out that BREEAM and LEED attempt to combine utility and energy trends, incorporating the environment, economy, and society into one holistic assessment system.

As indicated in Tables 2 and 8, the primary criteria for LEED certification cover a range of issues: energy efficiency of buildings, their usability, the efficiency of water and sewage management, the efficiency of materials and raw materials, the integration of the facility with the environment, the innovation and quality of design solutions, and regional priorities.

The analysis demonstrated that all certified buildings meet the strict standards outlined in the LEED program. They represent a variety of site-specific architectural solutions and programmed utility functions. Buildings designed and constructed under LEED standards are found around the world. The program originated in the USA, where the first certified building was completed, helping to expand the program.

The criteria for issuing a BREEAM certificate (Tables 5 and 8) cover a similar range of issues: energy efficiency, usability, efficiency of water supply and sewerage management, efficiency of materials and raw materials consumption, pro-environmental use of the territory, and pro-environmental innovation.

All BREEAM-certified buildings meet the rigor of the standards specified in the method. A characteristic feature of the buildings is the variety of their architectural solutions, considering the place and functionality. Tens of thousands of BREEAM-certified buildings for various purposes have been built and modernized in the UK. Almost every new office building in the UK is designed according to BREEAM standards and receives a certificate.

5. CONCLUSIONS

Our analysis of multi-criteria methods for assessing buildings for sustainability concludes that certification methods and programs are important for developers if they expect their visions to be successful.

Building evaluation standards and procedures generally address the so-called sustainability triad, i.e., environmental, economic, and social conditions. The design and evaluation standards defined in the methods should consider the location and forms of buildings, functional solutions, building materials, and technological systems for optimal building performance.

The methods of codification and definition of building evaluation standards, the features of evaluation procedures, and certification methods and programs are constantly improved, which is a prerequisite for developing quality standards for sustainable architecture.

The standards defined in the multi-criteria BREEAM and LEED methods provide a full picture of sustainable architecture encompassing environmental, economic, and social conditions. They apply to new and modernized residential and public buildings. We argue for the need to investigate new territories (including Kazakhstan, Russia, and Uzbekistan) to determine the relevance of the building evaluation methods and certification programs. Our study contributes to the popularization of sustainable architecture and standard codification, helping developers cultivate new projects.

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