Assessment of translate-ability of "green" standards requirements into a machine-readable format for automated verification

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Abstract. Application of BIM methods gradually extends to all stages of life cycle of construction object, including the stage of expert review when compliance to mandatory state standards is evaluated. Moreover, there have been recently recommendations established related to the environment impact of a construction object, or so-called "green" standards. Their wide implementation requires verification of information models not only for compliance with mandatory state standards, but also to recommend "green" standards in the framework of certification. A necessary condition for organizing this process is the translation of the relevant requirements of the "green" standards into a machine-readable format. In this viewpoint, it is important to assess this possibility and develop corresponding approaches. The purpose of this study was to assess the requirements of existing "green" rating systems for the ability to translate into a machine-readable format for further automated verification of information models. To achieve this goal, an analysis of existing "green" certification systems was performed. As a result, according to a set of criteria, the "green" systems were identified, the translation of the requirements of which is appropriate and promising. For these standards, the possibility of translating their requirements into a machine-readable format was evaluated and recommendations were made to improve it.

1. Introduction
Information modeling technology has been used in the construction industry for a long time, but it is only applied at the design stage of buildings or structures. Its successful implementation for project development has led to the extension of this approach to the remaining phases of the object's life cycle, including the stage of expert review.

Information models application to verify design results allows performing this process in an automated mode. In earlier studies [1], the main stages of testing information models for compliance with certain requirements were established. Their sequence is shown in figure 1.

The first and one of the most important stages is the translation of requirements from human-readable to machine-readable format. At the same time, in most studies [2-6], the provisions of normative documents related to the system of international or state standardization were considered as requirements.
However, in recent years, a significant number of requirements related to the impact of a construction project on the environment and contained in the so-called "green" certification systems have appeared. These systems are a set of ratings based on environmental requirements.

Currently, the existing systems of "green" certification are not mandatory and have recommendatory character. The decision to comply with certification is made on a voluntary basis by the management team of each specific project. However, the presence of a "green" certification is a serious competitive advantage of the project for interested participants: investors, developers, and tenants.

![Figure 1. Main stages of information model check](image)

Undoubtedly, control of building information for compliance with mandatory regulatory documents is a priority, but this approach will soon be relevant in the field of "green" and other standards. However, this will only be possible if the relevant requirements of the "green" standards are translated into a machine-readable format. This is why it is important to assess this possibility and develop appropriate approaches.

It is obvious that conducting certification for compliance with "green" standards in an automated mode will increase the impartiality of the assessment, reduce the impact of the human factor, thereby increasing its accuracy, reducing the time required to complete this procedure, and making more transparent to all participants.

There are several "green" rating systems worldwide today. Each system provides a specific methodology for guiding design processes and determining the level of achievement of environmental goals, as well as comprehensive tools for environmental assessment. These systems have certain similarities and differences depending on the goals and directions of evaluation.

Based on the above, the purpose of this study was to assess the requirements of existing "green" rating systems for the ability to translate into a machine-readable format for further automated verification of information models. To achieve this goal, the following tasks were defined:

1. Analysis of existing "green" certification systems.
2. Criteria definition and direct evaluation of the requirements of the "green" standards for the possibility of translation into machine-readable format.
3. Summary of the research results.
2. Methods
In this study, 11 rating systems were selected and analyzed, which were most reflected in papers on the topic of "green" certification.

1. BEPAC (Building Environmental Performance Assessment Criteria), Canada
The Canadian BEPAC system represents a set of construction requirements for evaluating environmental performance. It is applied only in Canada, as it does not have a strict systematization of indicators and ratings. BEPAC includes only a methodological list of possible environmental efficiency requirements without an algorithm for buildings assessment [7-9].

BEPAC consists of a comprehensive set of environmental requirements structured around five main directions: ozone layer protection, energy impact on the environment, indoor environmental quality, resource conservation, and location and transportation. The BEPAC quantitative requirements are organized into four modules. These modules can be viewed differently for the building and tenants. Design and management are considered at both levels. Each module focuses on five target areas.

2. BREEAM (BRE Environmental Assessment Method), United Kingdom
The BREEAM system is a voluntary environmental performance assessment system. BREEAM was developed in the UK in 1990 and is quite common around the world. BREEAM evaluates the efficiency of the construction project from the point of view of management and ecology (about 60 requirements of a point rating): energy efficiency, environmental pollution, resource conservation, safety of construction materials, waste disposal, rational use of territory and transport, etc. [10].

BREEAM is applicable to local building standards and practices due to a large number of requirements that may be excluded depending on the location. The system also takes into account the specifics and typology of the object, and when forming the final rating assessment, the emphasis is placed on different requirements [11-12]. Taking into account all the points and weight coefficients from the building site, a quantitative assessment is formed, which is then translated into a linguistic one.

The BREEAM system certifies a growing number of objects yearly, including in Russia. The developer company BRE Global is currently working on the transition of the system to a mandatory certification system worldwide.

3. CASBEE (Comprehensive Assessment System for Built Environment Efficiency), Japan
The CASBEE standard, which was developed in Japan, focuses on innovative and unique environmental construction projects. The concept of this standard is to recognize only phenomenal projects in terms of environmental performance. However, the application of the system and the range of building types are focused on the construction features of Japan and Asian countries [11].

A distinctive feature of the CASBEE standard is the assessment of not only the building itself, but also the construction site that belonged to it. In addition, the assessment system includes the contribution of the constructed building to the solution of global problems of humanity.

The standard evaluation system consists of a complex system of requirements in the form of quantitative indicators of innovative features and modern design methods. The system can be used both at the design stage, and at the stages of commissioning, operation, or after reconstruction [13-14].

The factors that limit the worldwide distribution and binding of the CASBEE standard are localization and orientation to the area of application, as well as a high level of evaluation and rating.

4. CESBA (Common European Sustainable Built Environment Assessment), Europe
The CESBA system is a pan-European assessment of the sustainable natural environment developed by the Association of European Union countries. The goal of CESBA is to harmonize sustainable assessment of the artificial environment across Europe [15-16].

The format of the CESBA certification is an extensive set of assessment tools that are used for project approval by expert participants from different countries of the European Union [17].

5. DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen), Germany
The DGNB system was developed in Germany in 2007 by the green building Society as design recommendations and a tool for evaluating the quality of the entire life cycle of a building in terms of environmental performance.

The DGNB assessment concept is based on a review of fifty years of building operation [11]. The certification contains 63 requirements grouped into six assessment categories: environmental quality, economic efficiency, socio-cultural qualities and functionality, technical equipment, process quality, location quality, and consideration of the building type in the form of an assessment matrix. As a result, the building receives one of three rating categories, which increases its commercial attractiveness throughout its life cycle [18].

6. Energy Star, USA

The Energy Star system is not a rating, but an energy efficiency mark approved in the United States and quite common worldwide [7]. Energy Star is the main mechanism for promoting environmentally sound American design. The main goal of this system is to reduce energy consumption as much as possible and minimize environmental emissions [19-20].

7. Green Star, Australia

The Green Star rating system was developed by the Australian Council for green buildings in 2002 based on the synthesis of two well-known standards "BREEAM" and "LEED" [12]. Therefore, Green Star also evaluates construction projects according to the requirements of environmental management and internal microclimate, but the difference is the orientation to the geographical location of the object [21].

Today, Green Star is used mainly for evaluating office buildings and business centers, and is also the Foundation for developing new standards for public, residential, entertainment buildings, medical and educational institutions [22].

8. HQE (Haute Qualité Environnementale), France

The French HQE system analyzes a building throughout its entire life cycle, i.e., throughout design, construction, operation and repair. The certification is focused on residential and non-residential buildings, as well as private houses. In addition, the system contains a special scheme for the project management system for urban planning and development [11]. Requirements for environmental indicators are organized into four categories, which together include 14 requirements [23-24].

The requirements are the same for all types of buildings, but they are distributed differently depending on the purpose and function of the item. The building project receives one of three types of evaluation for each goal. To be certified, an object must have a maximum of at least three requirements, and base level achievements must have maximum of seven categories. This rating system does not assign a weight coefficient to each requirement, unlike other popular systems [25].

9. LEED (Leadership in Energy and Environmental Design), USA

The LEED system was developed in the United States in 1998 and functions within the framework of American standards as a recommendation and voluntary standard that increases the prestige of the object and the developer [11]. It is used as a standard for evaluating sustainable building projects. The goal of LEED is a transfer of the entire construction industry to the energy-efficient and environmentally friendly design, construction and operation of buildings and structures.

The LEED concept is to minimize the environmental impact and consumption of all types of resources. Increased attention is paid to the location, production of "clean" materials, operation with reduced resource consumption, characteristics of the internal microclimate, rational use of waste, transport accessibility, the use of innovative solutions and environmental design [22].

LEED can certify various types of construction projects, renovation and reconstruction projects, as well as commercial interior projects, taking into account the specifics of the activity [26]. The authors of the LEED system are working on classification and adaptation of narrower areas: for residential buildings, for the development of adjacent territories, for trade facilities and educational institutions.

The work on LEED certification consists of six main stages, and the standard takes the assessment seriously enough. In some cases, the assessment requirements are roughly applied and not flexible, so
that many projects cannot receive part of the points for objective reasons. The work of designers and developers is often aimed at aspects of the project that will be exactly highly evaluated during certification. As a result, the object receives one of four levels of quality assessment, which will determine its environmentally sound status and increase its commercial attractiveness [27-28].

Despite the recommendatory nature of LEED certification, often the condition for obtaining a construction permit is the presence of a LEED certificate.

10. RuGBC (Russian green building Council), Russia

In Russia, development in the field of “green certification” is carried out within the framework of the activities of the public organization "Council for green construction", established in 2009. The work on developing own adapted environmental standards is based on the experience of other countries and existing standards, but taking into account the specifics of Russian design and construction [28-29].

11. SBTool (Sustainable Building Challenge)

The SBTool system was developed on the initiative of the international company "Green Building Challenge". The aim of the work was to develop energy and environmental efficiency standards that will be applicable both in international and national construction [30].

Representatives from twenty countries developed the SB method, which assumes an additional sub-standard in addition to the General standard of the company, taking into account national characteristics. The SB method covers three aspects of sustainability: environmental, economic, and social impacts [31]. The assessment can be carried out both for the planned building and for the existing one.

SBTool evaluates the environmental parameters of a building by assigning points, and each parameter has its own weight characteristic depending on the type of building.

The most wide-spread green certification systems are LEED, BREEAM and DGNB. Different countries mostly develop their own rating systems based on adaptations of existing common systems. Green certification systems can be used not only as rating tools, but also as guidelines for design, tools for comparing facilities, strategies and methodologies for construction, and documenting results and progress. All "green" rating systems are under constant improvement, developing, finding new ways of environmental efficiency and ways of distribution and implementation.

Currently, all green certification systems are voluntary, but there is a tendency to integrate environmental standards into project practice. If at least one of the “green” certification systems gets the force of law, all new buildings and structures will be as environmentally friendly (or "green") as possible.

3. Results

A method of criteria assessment will be applied to compare above-mentioned “green” standards from the viewpoint of translation into machine-readable format. In this review, eleven systems were considered, which is quite a lot, but these are not all the "green" standards available in the world. Considering large number and differences in the approaches and requirements implemented by these systems, it is necessary to assess the feasibility and prospects of translating their requirements into a machine-readable format. Moreover, if a certain system is applicable only for one specific country, building type, or considers an object only from the point of view of one group of environmental requirements, even if it is highly possible to translate its requirements into a machine-readable format, this will not be efficient. Therefore, the first group of criteria was selected, which assesses the prospects and feasibility of translation, consisting of the following criteria:

- distribution and application of the system simultaneously in several countries;
- applicability of the system for various construction projects;
- system assessment of several environmental directions simultaneously;
- Assessment algorithm and a final rating.

Regarding the last criterion, it is necessary to explain what meaning it has. The fact is that not each of the systems under consideration aims to issue a specific conclusion about compliance, non-
compliance or the degree of compliance with its requirements by calculating the appropriate rating. Some standards just contain recommendations to be applied on a construction site. However, from the authors' point of view, rating calculation allows providing more accurate assessment, and this is why this criterion was included in the review.

In addition, a second group of criteria was introduced to directly assess the possibility of translating the standard's requirements into a machine-readable format:
- systematization and grouping of environmental requirements;
- accuracy of requirements, i.e. the presence in the requirements of indicators of the object or its elements that need to be achieved;
- possibility to formalize requirements.

Table 1. Criteria of expediency and possibility of translation of “green” standards requirements into machine-readable format

| Code of the criterion | Name of the criterion                                                                 |
|-----------------------|---------------------------------------------------------------------------------------|
| **1. Criteria of translation expediency**                                           |
| K 1.1                 | Distribution and application of the system simultaneously in several countries       |
| K 1.2                 | Applicability of the system for various construction projects                          |
| K 1.3                 | System assessment of several environmental directions simultaneously                 |
| K 1.4                 | Assessment algorithm and a final rating                                              |
| **2. Criteria of translation ability**                                              |
| K 2.1                 | Systematization and grouping of environmental requirements                            |
| K 2.2                 | Accuracy of requirements, i.e. the presence in the requirements of indicators of the object or its elements that need to be achieved |
| K 2.3                 | Possibility to formalize requirements                                               |

Based on the results of the comparison of “green” systems with the criteria above, the table 2 contains basic information for forming appropriate conclusions about a particular system.

Table 2. Assessment of green standards requirements for the ability to translate into machine-readable format

| System | Rating concept | Criteria | Compliance with criteria                                                                 | Translate-ability into machine-readable format |
|--------|----------------|----------|------------------------------------------------------------------------------------------|-----------------------------------------------|
| 1      | BEPAC          | Number of criteria 5 requirements with 4 types of assessment | K1.1: used mainly in Canada (locality); K1.2: focus on office buildings; K1.3: requirements are considered for five topics; K1.4: there is no comprehensive rating and evaluation algorithm. | Expediency: low. In this regard, the translate-ability was not evaluated. |
| System | Rating concept | Criteria | Compliance with criteria | Translate-ability into machine-readable format |
|--------|----------------|----------|--------------------------|-----------------------------------------------|
| 2      | BREEAM         | Score with a weight coefficient, accounting for the type of building. The final quantitative assessment corresponds to the linguistic (one of five) | K1.1: international application; K1.2: used for most types of buildings; K1.3: a large number of requirements; K1.4: complex rating algorithm; K2.1: systematization and differentiation of requirements; K2.2: lack of specificity in the specified requirements; K2.3: formalization is possible if the requirements are specified. | Expediency: high. Translate-ability: medium (specification of requirements has to be provided). |
| 3      | CASBEE         | Rating of the building and surrounding area (5 classes) | 9 groups of requirements with a hierarchy of sub-criteria. Account the type of building | K1.1: focus on construction in Asian countries (locality); K1.2: targeting at unique objects; K1.3: criteria are considered for nine topics; K1.4: a complex rating algorithm that only works for unique objects. | Expediency: low. In this regard, the translate-ability was not evaluated |
| 4      | CESBA          | Methodology for coordination of the project | 5 groups of requirements with sub-criteria | K1.1: focus on European countries (locality); K1.2: used for most types of buildings; K1.3: subjective assessment; K1.4: no rating system. | Expediency: low. In this regard, the translate-ability was not evaluated |
| 5      | DGNB           | Evaluation of the building's 50 years of operation by criteria. The result is a positive level assessment (one of three) based on quantitative and linguistic translation | 63 requirements in 6 rating categories with a weighting factor | K1.1: international application; K1.2: complexity of building type accounting over the life cycle; K1.3: a large number of requirements; K1.4: complex rating algorithm; K2.1: systematization and differentiation of requirements. K2.2: not all requirements are specified; K2.3: formalization is possible if all requirements are specified. | Expediency: high. Translate-ability: medium (specification of requirements has to be provided). |
| System       | Rating concept                        | Criteria                          | Compliance with criteria                                                                                     | Translate-ability into machine-readable format |
|--------------|---------------------------------------|-----------------------------------|--------------------------------------------------------------------------------------------------------------|-----------------------------------------------|
| Energy Star  | Energy efficiency sign                | Energy efficiency indicators      | K1.1: international application; K1.2: universality of assessment requirements; K1.3: limited assessment area (energy efficiency); K1.4: no strict assessment standards, no assessment algorithm or rating system; K2.1: lack of systematization and differentiation of requirements; K2.2: lack of specificity in the specified requirements; K2.3: formalization is possible if the requirements are specified and the rating system is developed | Feasibility: average. Translate-ability: low (systematization, differentiation and specification of requirements are required, as well as the development of a rating system) |
| Green Star   | Rating system by aggregate LEED and BREEAM | 62 requirements                   | K1.1: application mainly in Australia; K1.2: focus on office buildings; K1.3: no grouping of criteria by group (topic); K1.4: lack of strict assessment standards, rating algorithm at the stage of completion, gaps in the assessment system. | Expediency: low. In this regard, the translate-ability was not evaluated |
| HQE          | The system evaluates the efficiency for a variety of purposes. The final score is assigned based on a set of goal ratings (3 ratings) | 14 requirements in 4 groups       | K1.1: not limited to application within a specific country; K1.2: difficulty in establishing the relationship between the building type and the list of goals; K1.3: limited number of criteria; K1.4: complex rating algorithm. | Expediency: low. In this regard, the translate-ability was not evaluated |
| System  | Rating concept | Criteria | Compliance with criteria | Translate-ability into machine-readable format |
|---------|----------------|----------|--------------------------|-----------------------------------------------|
| LEED    | The quality is determined by the final score on a 100-point system. Each range corresponds to one of the four certification levels. | 62 requirements in the structure of 7 sections. | K1.1: not limited to application within a specific country; K1.2: requirements for objects of various purposes; K1.3: large number of criteria, but the not flexible applicability of some; K1.4: complex 6-stage rating algorithm; | Expediency: high. Translate-ability: medium (specification of requirements has to be provided). |
| RuGBC   | Analysis of the Council of experts on green construction | Summary expert assessment | K1.1: only applicable in Russia and CIS countries; K1.2: universality of expert assessment; K1.3: lack of requirements and systematization of assessment; K1.4: no strict assessment standards, no assessment algorithm or rating system. | Expediency: low. In this regard, the translate-ability was not evaluated |
| SBTool  | Structure of various criteria for evaluating buildings for sustainable construction | 8 generalized groups, the number of requirements varies depending on the object | K1.1: not limited to application within a specific country, but there are difficulties in accounting for national requirements; K1.2: used for most types of buildings; K1.3: criteria are considered for eight topics. The number varies depending on the type of building; K1.4: no strict assessment standards, no assessment algorithm or rating system. | Expediency: low. In this regard, the translate-ability was not evaluated |

Thus, according to table 2, it can be concluded that the most appropriate way is to translate the requirements of the BREEAM, DGNB and LEED systems. These systems are probably the most advanced, since they contain requirements for a variety of environmental areas for different types of buildings, and can also be used for many countries. Requirements translate-ability into machine-readable format were performed to these standards. Based on the results, it can be concluded that all these systems have a high degree of differentiation and systematization of requirements. However, these systems have common features like the lack of accurate definitions in the requirements, blurred wording and uncertainty in their interpretation. Thus, the work on their formalization and translation can only be possible after appropriate measures aimed at specifying the requirements. In addition, it
may be promising to perform automate compliance to the requirements of the Energy Star system, which, although its limited assessment area, is widely used to improve energy efficiency at the international level. It is also worth noting that the improvement and development of other systems can also increase the feasibility of translating their requirements into a machine-readable format for organizing automated verification of information models.

4. Conclusions

The scope of building information modeling functions is expanding every day in various directions, which in certain degree improve the quality of design and construction, as well as create new tools. One of these tools is an automated verification of the information model for compliance with the requirements of "green" standards. This process will ensure the dissemination of the concept of environmental construction, which will eventually have a positive effect on the global environment and society as a whole.

To verify the information model, the requirements of a specific "green" standard should be presented in a format that is possible for software comparison of the model parameters with the certification conditions. The implementation of this process is preceded by the translating of the "green" standard requirements into a machine-readable format, but not all "green" standards are able to be translated. This study reveals a comprehensive analysis of "green" standards, including the possibility of integration with information modeling for the organization of automated checks. The main conclusions of the study are as follows:

1. All rating systems have many common features and significant differences. The differences are in the purpose of certified objects, in the directions of environmental assessment, in the evaluation and rating algorithms, and in the localization of the application of the standard. After reviewing the most popular systems, we can conclude that each system has its strengths and weaknesses relative to the area of interest. It is quite difficult and even senseless to determine the best system, since a specific "green" system has to correspond to each task, object type, or project goal in specific country. The same object can get different ratings in different systems.

2. It is necessary to determine whether a particular system can be represented in machine-readable form to select the "green" system (-s) that can efficiently verify the information model in an automated way. First, it is essential to determine the feasibility of translating for a particular system, then to evaluate the possibility of translating it into a machine-readable format. Both stages are based on the preliminary formation of criteria for the feasibility and possibility of translation. According to the results of the analysis of 11 "green" systems, only 3 systems are promising for further implementation in the process of automated environmental assessment based on information modeling. However, even these systems can only be formalized if certain adjustments are made to specify and systematize criteria within the standard.

3. Complexity of presenting green certification systems in a machine-readable format paves the way to new research directions in the field of sustainable construction and the search for new methods and algorithms for data formalization. To speed up the process of translating green certification systems and minimize problematic issues, it is necessary to work on several areas simultaneously: green certification, data formalization, and verification of information models.

This study is an important stage in the research of the environmental efficiency of construction and the possibilities of building information modeling with maximum automation in operation. The results of the work form the methods and limiting factors for implementing automated verification of "green" buildings for compliance with the requirements of rating systems.

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