Parameters related to building components’ life-cycle analysis in methods for buildings’ environmental performance assessment

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Abstract. In this study, the integration of factors related to life cycle analysis and assessment of building materials and components in the context of widely used methods applied for the evaluation of buildings’ environmental performance is examined. The reviewed assessment systems are BREEAM, LEED, CASBEE, DGNB, HQE and SBTool, with the analysis being focused on their versions referring to new office buildings. Issues related to the content and type of indicators and criteria used for the evaluation of factors referring to life cycle assessment, as well as to the way these rating elements are introduced into the structure and the evaluation process of the aforementioned methods, are examined. In this context, the relative standards and the appropriate –if any– databases and tools mentioned within each method are also demonstrated. The results of this work are systematically presented. The analysis is complemented by the examination of the inclusion of life cycle assessment-related factors in Level(s), a common European framework currently under trial. The present study aims at contributing to the identification of similarities and differences and at highlighting the current trends among widely used buildings’ environmental performance rating systems with regard to the approach they adopt considering building components’ life cycle assessment.

1. Introduction
A substantial part of buildings’ environmental impacts (resources consumption and burdening emissions) are related to building materials’ and components’ life cycles. Indeed, not only the environmental profiles of materials at the time of their integration into the building, but also aspects related to their efficiency, maintenance and replacement during the building’s life cycle can be of importance for the whole building’s performance. Hence, the consideration of building materials’ impacts related to their life cycle in the process of their selection is a significant element of the design stage when the final aim is an environmentally friendly building. The adoption of several strategies can facilitate this process (selection of materials appropriately labelled, preference to local and/or recyclable materials, etc.), with a main approach being the implementation of building materials’ life cycle assessment methods and/or the consideration of such analyses’ results; this approach can ensure at least the awareness of the selected materials’ impact. Elements of this nature (i.e. related to the consideration of building materials’ and components’ life cycle-related environmental impacts) could not but be included in the methods used for the assessment of buildings’ environmental performance. Indeed, these methods, characterised by varying –to a lower or higher degree– structures, complexity
levels, philosophies of assessment and criteria for the evaluation of different issues [1-17], employ, in their vast majority, a holistic approach to buildings’ performance. In the context of this approach, which is oriented towards the examination of all the axes of a building’s construction, operation and end-of-life, parameters referring to issues related to building materials’ and components’ life cycle assessment are included among the evaluated elements.

The inclusion of factors related to building materials’ and components’ life cycle assessment in the structure and in the evaluation process of widely used methods applied for the assessment of buildings’ environmental performance is the subject of investigation in this study. Specifically, the present work is based on a systematic review of the way such factors are integrated in the context of BREEAM, LEED, CASBEE, DGNB, HQE and SBTool. The reviewed versions of these methods are the ones referring to new office buildings (with, where possible, an international scope of application) [18-24]. The reason behind this choice lies on an effort to review systems dealing with “comparable”, to the extent possible, objects of assessment (for example, the design and construction of buildings of domestic use are usually characterised by a strong integration and expression of local practices and architectural traditions; therefore, these buildings are of reduced comparability across different parts of the world). The review is focused on parameters related to the criteria and indicators (content and type) used in the context of each one of the examined methods for the consideration of building materials’ and components’ life cycle analysis and assessment. Issues related to these evaluation elements’ integration into the general structure of each method are also referred to. The examination of the inclusion of life cycle assessment-related factors in Level(s) [25-26], a common European framework currently under trial, complements the presented analysis. Although of a differentiated philosophy in comparison to the other reviewed methods, this framework is included in the study as a potential future common European denominator for the integration of buildings’ environmental performance assessment into the construction practice. At this point, it is noted that in the context of the present critical review, emphasis is placed on the examination of the integration of parameters related to life cycle analysis and assessment (LCA) and its results into the evaluation process of each method; LCA is dealt with in this study as a technique, a methodology for the calculation/estimation of building materials’ and components’ environmental impacts. Several issues related to the environmental impact of materials’ and components’ life cycle (resilience, recyclability, etc.) are examined in some methods with the use of criteria other than the ones related to LCA; the systematic presentation of these criteria are outside the scope of the present review. The presented study, a part of which is to a degree based on [27], aiming at contributing to the identification of similarities and differences among the various environmental performance rating systems with regard to the approach they adopt to building materials’ and components’ life cycle assessment, is structured in two main parts. Initially, main characteristics of the examined methods are demonstrated. In the second part the factors related to the integration of LCA-related criteria are presented for each method. Finally, synoptic conclusions are discussed.

2. Buildings’ environmental performance assessment methods and tools

The methods selected to be studied are among the most well-known tools used for the assessment of the buildings’ environmental performance. As mentioned in the Introduction section, the present review focuses on the versions of these tools regarding buildings of the tertiary sector and, specifically, office buildings (new construction). General information regarding the examined methods as well as characteristic elements of the assessment process of each one of them are presented in tables 1-2. Analytically, information referring to the development of the examined method (e.g., organisation that developed or/and is responsible for the system, the publication years of the first published and the studied version of the method respectively), to the scope of the examined version (i.e. the buildings’ uses and the building’s life-cycle stages covered by this version) and to issues regarding the assessment approach of each method (the environmental sections considered, the indicator –index, percentage, etc.– used to express the building’s performance and forming the basis of the assessment, the classification categories of buildings depending on this final “score”) is illustrated in tables 1-2.
Level(s), as a differentiatated framework currently under trial, is not included in tables 1-2 and is presented in a separate paragraph.

2.1. BREEAM
Building Research Establishment’s Environmental Assessment Method (BREEAM) is chronologically the first of the studied methods that was published. The first scheme was developed to be used for the environmental performance assessment of office buildings in United Kingdom. Nowadays, with the currently available versions of this method, the assessment of domestic and non-domestic buildings at various stages of their life cycle, inside and outside the borders of United Kingdom, is possible. In fact, even groups of buildings can be assessed with the use of the corresponding scheme (BREEAM Communities). BREEAM consists of a number of assessment criteria, which are organized into assessment issues. In BREEAM International for New Constructions [18] these assessment issues are classified into ten (nine sections plus “Innovation” section) environmental sections (table 1). A specific number of points is available in the context of each criterion. These points are awarded depending on whether and to which degree the building meets the various requirements of the criterion. At this point, it should be noted that there are minimum performance limits in the framework of specific criteria (these performance levels are required to be achieved for the assessment to proceed), so that fundamental environmental issues are not overlooked. The percentage of the available points of each section (except Innovation) that are awarded to the building is multiplied by a weighting factor. These products are summed all together giving a final score. The contribution of the Innovation section is added to the final score and the derived sum is used for the building’s rating and classification (table 1).

2.2. LEED
Leadership in Energy and Environmental Design (LEED) is one of the most well-known methods for the evaluation of the buildings’ environmental performance. Since the release of the first pilot version, there have been several further developed versions launched. Nowadays, the numerous schemes of LEED v4 methodology can be used for the estimation of the environmental performance of, among others, homes, non-residential buildings, complexes of buildings (LEED for Neighborhood development, Communities) and cities. The available schemes cover different buildings’ uses and life-cycle stages. Furthermore, LEED v4 can be used internationally with the application of certain adjustments and/or the adoption of alternative approaches to certain issues (e.g., https://www.usgbc.org/resources/leed-v4-bdc-alternative-compliance-paths-europe-april-2018). The studied in this work scheme, LEED v4 for Building Design and Construction [19], is composed of a multitude of criteria (the compliance with the requirements of some of them is a prerequisite for the assessment), which are classified into eight environmental categories (table 1). Every criterion (apart from the prerequisite ones) is accompanied by a number of available credits, which are “earned” by the building based on whether the related performance levels are achieved. The maximum number of available points in each category differs depending on the buildings’ location (e.g., country) and depicts its importance. The final ranking of the building is based on the sum of the credits that are awarded to the building (table 1).

2.3. CASBEE
Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is a method for the assessment of the environmental performance of the buildings, the computational implementation of which is a spreadsheet-based tool. The method has been developed since 2001, with the first tool (for the evaluation of office buildings) being completed in 2002, and is widely used in Japan. Currently, CASBEE schemes are available for the rating of the environmental performance of buildings at different life cycle stages (single dwellings, residential and non-residential building), as well as for projects of a larger scale (CASBEE for Urban Development CASBEE for Cities). Also, schemes related to specific issues (e.g., urban heat island) have been developed. CASBEE for New Construction 2014 [20] comprises of an extended set of criteria, covering all the aspects of buildings’ environmental
The number of points that are awarded tags of their life cycles are available; districts performance. These criteria are classified into subcategories, which, are sorted into larger assessment categories (table 1). Each of the latter is a constituent part of either the factor Q (environmental quality of building) or the factor LR (environmental load of building). The assessment score for each criterion is based on a five-level assessment scale. The number of points that are awarded to the building for each criterion is dependent on the performance level, the requirements of which are fulfilled (e.g., 4 points for level 4). Generally, the lower level corresponds to the minimum requirements of regulations related to buildings in Japan. The score of each criterion is multiplied by this criterion’s weighting coefficient; the weighted sum of the scores of the criteria constituting a sub-category equals this sub-category’s score. An analogous procedure is followed for the calculation of the score of the categories. The values of the factors Q and LR are calculated as the weighted sum of the scores of the categories belonging to each one of them. These values (Q and LR) are used for the estimation of the BEE indicator and the classification of the building (table 1).

Table 1. Basic elements of the examined systems’ structure and evaluation method (BREEAM, LEED and CASBEE).

| Studied version and publication year | BREEAM International New Construction, 2016 | LEED v4 for Building Design & Construction, 2018 | CASBEE for Building (New Construction), 2014 |
|-------------------------------------|--------------------------------------------|-----------------------------------------------|---------------------------------------------|
| Organization / origin              | Building Research Establishment (BRE) / U.K. | U.S. Green Building Council (USGBC) / U. S. A. | Japan Sustainable Building Consortium (JSBC) / Japan |
| Publication year of the first version | 1990                                      | 1998                                          | 2002                                         |
| Buildings’ uses covered by the studied version | non-residential buildings | new construction, core and shell, schools, retail, data centres, warehouses and distribution centres, healthcare and hospitality | offices, schools, retailers, restaurants, halls, factories, hospitals, hotels, apartments |
| Life cycle stages covered by the studied version | design, construction and post-construction stages | all the life cycle stages | design and construction stages |
| Environmental sections' factors (Q and LR) and categories of assessment | - Management, Health and Wellbeing, Energy, Transport, Water, Materials, Waste, Land use and Ecology, Pollution, Innovation | - Location and Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation, Regional Priority | Q: Environmental Quality, Q1. Indoor Environment, Q2. Quality of Service, Q3. Outdoor Environment, LR: Environmental Load Reduction of Building, LR1. Energy, LR2. Resources and Materials, LR3. Off-site Environment |

*In tables 1-2, this term is used to express in a unified way the major thematic categories, into which the parameters examined by each system are organised; the terms used for these large categories in the structure of each method are different and are presented as underlined “titles” in the respective cells.

2.4. DGNB
Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) is an assessment system, used for the evaluation of buildings’ environmental performance; its initially published version was used for the evaluation of new office and administrative buildings in Germany. Currently, schemes for the assessment of buildings of various uses at different stages of their life cycles are available; districts
can also be assessed with the application of the corresponding scheme. DGNB methodology can be implemented internationally, either with the use of universal criteria based on European standards or via the adaptation of the system to the local regulations and conditions. In 2018 a new version was launched (table 2), which was, among others, aimed at complying with the indicators included in Level(s) framework. In this version, the criteria used to assess the buildings’ performance are organised into six quality sections (table 2). Very few of the criteria are prerequisite (i.e., their requirements should be met to complete the assessment with DGNB system). Depending on the performance of the building with regard to the indicators expressing the criteria’s requirements, up to 10 points can be awarded to the building for each criterion.

Table 2. Basic elements of the examined systems’ structure and evaluation method (DGNB, HQE and SBTool).

| Studied version and publication year | DGNB                  | HQE scheme construction performance NR01jan 2016 [22] | SBTool 2015 Generic MAX DSN 4Sep15 [23-24] |
|-------------------------------------|-----------------------|-----------------------------------------------------|---------------------------------------------|
| Organization / origin               | German Sustainable Building Council (DGNB) / Germany | Haute Qualité Environnementale-High Environmental Quality (HQE) / France | under the responsibility of international initiative for a Sustainable Built Environment (iiSBE) / international |
| Publication year of the first version | 2008                  | 2005                                                | as GBTool: 1998 (development process beginning in 1996 [28]) SBTool: 2002 |
| Buildings’ uses covered by the studied version | office, education, residential, hotel, consumer market, business premises, logistics, production, shopping centre | non-residential buildings | hospitality, library, offices, K to 12 school, resto/cafeteria, retail, supermarket, shopping centre, theatre-cinema, lobby, public space, parking and service area |
| Life cycle stages covered by the studied version | All life cycle stages | Design and construction stages | All the life cycle stages and pre-design stage |
| Quality Sections                    | Quality Sections      | Themes and Targets                                  | Performance Issues                          |
|                                     | - Environmental Quality | Theme: Energy                                      | A. Site Regeneration and Development, Urban Design and Infrastructure |
|                                     | - Economic Quality     | Target: 4. Energy                                    | B. Energie and Resource                      |
|                                     | - Sociocultural and Functional Quality | Theme 2: Environment  | C. Consumption                              |
|                                     | - Technical Quality    | Targets: 1. Site, 2. Components, 3. Worksite, 5. Waste, 6. Water, 7. Maintenance, | D. Indoor Environmental Quality |
|                                     | - Process Quality      | Theme 3: Health                                     | E. Service Quality                          |
|                                     | - Site Quality         | Targets: 8. Spaces Quality, 9. Air Quality, 10. Water Quality, | F. Social, Cultural and Perceptual Aspects |
|                                     |                        | Theme 4: Comfort                                    | G. Cost and Economic Aspects               |
|                                     |                        | Targets: 11. Hygrothermal Comfort, 12. Acoustic Comfort, 13. Visual Comfort, 14. Olfactory Comfort | |
| Expressions of the building’s performance | Total- and Minimum Performance Indices, expressed as percentages (%) | Number of gathered stars | Relative performance score (the values of this score are in the range of the method’s assessment scale) |
|                                     |                        |                                                      | A+, A, B+, B, C+, C, D+, D, E, F, G (A+→G: decreasing performance) |
| Ranking of the building             | Platinum, Gold, Silver, Bronze | Exceptional, Excellent, Very Good, Good, Pass | |

The weighted sum of the points given for each criterion of a section divided by the weighted sum of the available points leads to the score of the quality section. The final score is the outcome of the
weighted sum of the scores of the sections (each one of the sections’ scores is multiplied by the section’s weighting factor). Based on the “minimum performance index” (related to the score of each section) and on the “total performance index” (final score), the building receives an award expressing its rated performance (table 2).

2.5. **HQE**

Haute Qualité Environnementale (HQE) is a system for the evaluation of the environmental performance of buildings developed by a French non-profit association (table 2). The first scheme was launched in 2005 and was designed for the assessment of new or renovated terrestrial buildings in France; ever since, different schemes have been developed for the assessment of buildings of different uses (under construction, renovated or in use). Nowadays, CERWAY (https://www.cerway.com/) is in charge of the evaluation and rating of residential and non-residential buildings and of the sustainable urban planning in territories outside France. The version of the method that is included in the present study [22] is related to the non-residential buildings that are under construction internationally (table 2). The assessment criteria are organized into sub-targets, which are classified into 14 performance targets (table 2). The four environmental themes of the studied version consist of these 14 performance targets. The framework of each criterion is based on certain requirements and conditions, with the fulfillment of which points are awarded to the building. It is noted that criteria, the fulfillment of the requirements of which is mandatory for the evaluation with HQE, are included in all the targets. The total sum of the points of the criteria, which belong to each one of the targets, is the final score of this target. The comparison of the gathered points in the context of each target with the respective available points results to the characterization of the target as “PR” (compliance with the prerequisites) “Performing” or “High Performing”. Finally, 1 to 4 stars are awarded for each theme depending on the performance of its constituent targets (the process differs among the themes). The total number of gathered stars is the measure for the classification of the building (table 2).

2.6. **SBTool**

Sustainable Building Tool (SBTool), the evolution of GBTool, is an international framework used for assessing the environmental performance of buildings; in fact, it is a generic system that can be adjusted to varying priorities, conditions and regulations for locally and/or nationally relevant versions of the tool to be created and for site-wise insightful assessments to be produced. SBTool is continuously evolving under the responsibility of iiSBE since 2002. The computational tool of the method consists of two spreadsheet-based files that are linked with one another. Regarding the assessment structure of the system, SBTool consists of a large number of criteria. Some of these criteria are mandatory; the performance of the building regarding these criteria should surpass a certain level. The criteria belong to performance categories and these categories are organized in seven performance issues (table 2). It is noted that the number of (active) criteria that are taken into consideration for the building’s evaluation depends on the scope of the assessment and on the life-cycle stage, for which this evaluation takes place. The criteria are assessed on a five-level scale; specifically, depending on the level of the performance achieved, as this performance is expressed by the respective indicator, a score of -1 to 5 is assigned in the context of each criterion’s assessment. The minimum score for the mandatory items previously mentioned can be set to a value equal to 2 or higher. The score of each criterion is multiplied by a weighting coefficient and summing the products all together results to the score of the larger entities of the assessment structure (performance categories and issues), as well as to the final score. This score is the basis for the ranking of the building (table 2).

2.7. **Level(s)**

Level(s) is a common European framework for buildings’ environmental performance assessment that is currently under trial [25-26]. This framework can be used by individuals, involved in the scientific and applied fields of construction, with different levels of expertise. An important difference of Level(s) from the rest of the methods reviewed in this study is that Level(s) is not used for the ranking
of the building. On the contrary, Level(s) is a reporting tool setting out the important aspects of sustainable development of the buildings. This framework is suitable for the assessment of office and residential buildings (individual buildings or groups of buildings) at the design, implementation, completion or operation stage. Depending on the intended level of accuracy, three options are available for the assessment (“levels of assessment”). Level(s) framework consists of three thematic areas (“Life cycle environmental performance”, “Health and Comfort”, “Cost, value and risk”), which are composed of six macro-objectives (“Greenhouse gas emissions along a buildings life cycle”, “Resource efficient and circular material life cycles”, “Efficient use of water resources”, “Healthy and comfortable spaces”, “Adaptation and resilience to climate change” and “Optimised life cycle cost and value”). These macro-objectives are comprised of indicators and/or life-cycle tools that are provided for the evaluation of the buildings’ performance. A different aspect of the buildings’ life cycle is evaluated through guidance provided in each indicator or tool and the reporting of the related results is mandatory. The information extracted from the life cycle tools (e.g. life cycle scenarios configuration) is used in the context of some indicators. The final outcome is the configuration of tables, which consist of data regarding the examined buildings’ environmental performance.

3. Life Cycle Assessment in the context of the examined assessment methods

In this section, the LCA parameters examined in the context of the reviewed assessment methods (more specifically, of the examined versions/schemes of these methods) are systematically presented; information related to the indicators and the criteria used in the assessment structure of each method (standards forming the basis of the evaluation, main content and type of criteria, etc.) are referred to. It is noted that the integration of EPDs in the criteria employed in each one of the reviewed methods is also presented. The inclusion of EPDs in the presented analysis is based on the facts that (a) these labels are (at least most of their types) produced on the basis of life cycle assessments and (b) when present in the examined methods, they are usually part of the reviewed LCA parameters. The presentation of the review results for each scheme is organised in a way that depends on the available information.

3.1. BREEAM

In BREEAM International New Construction 2016, the LCA-related considerations are referred to mainly in the context of the environmental section “Materials”; specifically, these parameters are examined within the environmental issue “Mat 01. Life cycle impacts”. In table 3, the main factors that are examined in the context of this issue and are related to LCA are listed; for each factor, the thematic core of the criteria that are connected to its assessment is described (second column of table 3) and the type of the corresponding requirements for compliance is mentioned. Moreover, in the last column of table 3 (lightly shaded), the standards related to all the listed criteria and are mentioned in the examined scheme’s manual are presented; in addition, the LCA tools/methods that are characterized by [18] as appropriate for the relative calculations are included in this column. Finally, this column includes also a reference to the standards, which the EPDs should comply with in the context of the examined method’s requirements (since these declarations are somehow participating in the assessment process of the listed factors); in the case of BREEAM, the selection of products verified by EPDs is autonomously evaluated and rewarded.

The issues included in the first factor listed in table 3, i.e. the robustness of the applied LCA tool and the scope of the assessment (regarding the number and the type of building components examined), are assessed with the use of BREEAM International Mat 01 calculator. The score calculated by this tool, expressed as a percentage of the points available that are achieved (provided of course that its mandatory preconditions are met), forms the basis for 1-5 points to be awarded to the building. The coverage of at least 5 products by EPDs gives 1 point to the building; here it is worth mentioning that the use of products with EPDs from different construction products sectors is encouraged. The parameters examined in this paragraph may give up to 6 points to the building, which account for the 50% of the available points in the “Materials” environmental section. Moreover, the achievement of exemplary performance levels with regard to these parameters results in the increase
of the final score (“Innovation” section). It is noted that the use of recycled aggregates is examined in another section of the reviewed method; the examination of this issue is based on indicators that are not connected to the LCA factors dealt with in this paragraph.

A noteworthy element of the approach adopted by BREEAM International New Construction 2016 with regard to LCA-related parameters, is that it is focused on the availability of reliable data for the environmental impact of construction products and materials. In this context, it is the derivation process or/and the sources of such information (use of calculation tools that are robust enough, adequate scope of assessment and reliability of sources) that are mainly examined.

### Table 3. LCA-related parameters in the examined version of BREEAM.

| Examined factor | Thematic core of the related criteria/indicators | Type of conditions and requirements included in the criteria/indicators | Standards for LCA and EPDs & appropriate / proposed LCA tools or/databases |
|-----------------|-------------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|
| The use of appropriate life cycle assessment tools for the specification of the environmental impacts of construction materials | Conduction of LCA with the use of a robust tool (the methodology and the database of the tool are evaluated) | Mainly descriptive (compliance with conditions, mandatory or non-mandatory, for the methodology and the database of the applied LCA tool that are listed in the related BREEAM calculator) | •LCA tools: specific reference is made to IMPACT - Integrated Material Profile and Costing Tool (www.IMPACTwba.com) and to the fact that other LCA tools approved and evaluated by BRE Global can be used. |
| Environmental Product Declarations | Inclusion of main building elements in the performed LCA (adequate scope of assessment) | Mainly descriptive (inclusion in LCA of several building components, at least those indicated as “mandatory” in the related BREEAM calculator) | •EPDs must conform to either EN 15804, ISO 14025 or ISO 21930. |
| Environmental Product Declarations | Use of construction products covered by verified EPDs | Descriptive and quantitative (at least 5 products should be covered by EPDs for the corresponding points to be awarded to the building, etc.) | |

b This calculator, named BREEAM International Mat 01 calculator, is a spreadsheet-based tool.

c Not all building elements included in the relative field of BREEAM International Mat 01 calculator are characterized as mandatory.

### 3.2. LEED

In LEED v.4 [19], the LCA-related considerations are dealt with mainly in the context of the environmental category “Materials and Resources”. In table 4, the factors that are evaluated in the context of [19] and are related to LCA are presented. The structure of table 4 is the same as the one of the previously presented table 3.

In the context of the relative LCA-based criterion (fourth row-second column of table 4), the requirement stated in the examined version of LEED v.4 [19] consists in the improvement of the assessed building’s performance in relation to a baseline building with comparable characteristics. The required improvement is the at least 10% reduction of the assessed building’s impact with regard to at least 3 out of a catalogue of environmental impact categories. With regard to EPDs, the provision of products with EPDs from different manufacturers is promoted. The fulfillment of the conditions referred to in this section (when the performance of LCA is the chosen option in the context of the first examined factor – table 4) provides 5 points, which corresponds to a little less than 40% of the points available in the “Materials and Resources” environmental category for office buildings in the studied version of LEED.

It is noted that in the case of the examined scheme, the LCA-related considerations include the comparison of the assessment’s results with a “reference” building (i.e. the actual relative performance
is assessed); furthermore, the performance of an LCA study is treated as an alternative option in the context of a criterion (the points available for this criterion may be awarded through the selection and application of another strategy/option).

Table 4. LCA-related parameters in the examined version of LEED v.4.

| Examined factor | Thematic core of the related criteria/indicators | Type of conditions and requirements included in the criteria/indicators | Standards for LCA and EPDs & appropriate / proposed LCA tools or/and databases |
|-----------------|-------------------------------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Reduction of the building’s life-cycle impact | Reuse of existing historic buildings\(^d\) | Descriptive (maintenance of historic buildings, demolition after approval by board, etc.) | - LCA: it is required that the LC Assessments of both the examined and the baseline buildings are conducted with the use of the same tool; also, the data sets should comply with ISO 14044. |
| | Maintenance, renovation & reuse of blighted/abandoned buildings\(^d\) | Quantitative and descriptive (surface area of building elements to be maintained, etc.) | - EPDs must conform to either EN 15804, ISO 14025 or ISO 21930, product-specific declarations should comply with ISO 14044. |
| | Reuse of materials (reused or salvaged on- or off-site)\(^d\) | Mainly quantitative (percentage of the completed project’s surface reused) | |
| | New construction: LCA conduction for the structure & the enclosure showing improved performance compared to a baseline building | Mainly quantitative (required percentages of reduction in a range of specified environmental impacts, etc.) | |
| Disclosure and optimization of building materials and products: environmental product declarations | Use of several construction products covered by EPDs | Descriptive and quantitative (number of products covered by EPDs compliant with specified standards, etc.) | |
| | Use of products with proven reduced environmental impact | Descriptive and quantitative (% by cost of the products permanently installed that have improved performance or are compliant with specific frameworks, etc.) | |

\(^d\) These axes of compliance criteria are referred to here because, in case they are applicable, they are alternative options to the conduction of LCA.

3.3. CASBEE
In CASBEE [20], the performance of life cycle analyses and assessments is not directly evaluated as a separate criterion within the main structure of the tool. In fact, an explicit reference to analyses referring to the impact of building materials’ and products’ life cycles is made in the context of the assessment sub-item “LR3.1 Consideration of global warming”. The evaluated performance aspect in “LR3.1” is the amount of effort targeted towards the consideration of global warming. Under this prism, provisions aiming at reducing the buildings’ LCCO\(_2\) are positively assessed. The amount of LCCO\(_2\) is calculated for the whole life cycle of the building that is assessed (construction, operation and end-of-life stages) and is compared with a reference value that is derived for a “standard” building. The reduction percentage achieved defines the points that are awarded to the building. The related analyses, at least for the “standard” calculation\(^1\), are to a considerable degree automated in the method’s computational tool, in the sense that they are based on reference and statistical information already prepared and databased (a simplified approximation method is used). The life cycle analyses

\(^1\) An “individual” calculation of LCCO\(_2\), i.e. a more detailed analysis based on data gathered by the assessor(s) and conducted according to “any published LCA method” [20], is permissible.
of building materials and products are a constituent part of the estimation of the construction stage – related LCCO₂. In [20] it is stated that the reference values for LCCO₂ (LCA –related data) have been calculated with the use of AJI’s (Architectural Institute of Japan) LCA guidelines for buildings (“AIJ-LCA&LCW_ver.5.00”). The improved performance of the assessed building in the field of the embodied CO₂ of building materials and products (compared to the standard one) is calculated with the help of the inputs provided in the context of other criteria and assessment sub-items included in the structure of the tool. At this point, it is worth mentioning that some of those criteria are directly related to the environmental impacts of the building products (e.g., “LR.2.2.2 Continuing use of existing structural frame”, “LR.2.2.3 Use of recycled materials as structural materials”) but do not incorporate the LCA process as a constituent element. Finally, it is noted that “LR3.1 Consideration of global warming” sub-item is given a relative weight of 33% (default value in [29]) within the category “LR3 Off-site Environment”, which has a contribution of 30% to the score of factor LR (environmental load reduction of the building).

In the CASBEE scheme examined [20], the label related to the environmental impacts of the building products and is involved in some of the method’s criteria is Eco Mark, a type I environmental-label (the Eco Mark program follows ISO 14020, ISO 14024 - https://www.ecomark.jp/english/syoukai.html). Reference to the selection of materials and products listed as EcoMark Products is made, among others, in the context of criteria assessing the use of recycled materials.

3.4. DGNB

The parameters related to LCA in DGNB are examined in the context of the criterion “ENV1.1. Building life cycle assessment”, which belongs to the category “Environmental Quality”; this criterion, which includes other indicators as well, accounts for a share of 9.5% of the building’s final score (office buildings). The factors that are related to LCA and are examined within DGNB method are tabulated in table 5.

| Examined factor | Thematic core of the related criteria/indicators | Type of conditions and requirements included in the criteria/indicators | Standards for LCA and EPDs & appropriate / proposed LCA tools or/and databases |
|-----------------|-----------------------------------------------|-------------------------------------------------|--------------------------------------------------|
| Consideration of life cycle assessments results in the planning process | Integration of life cycle assessments in the planning process | Descriptive and quantitative (LCA performed at various stages of the planning process, comparison of potential variants during planning with regard to their environmental impacts, etc.) | +LCA: -- DIN EN 15978 is referred to as the basis for the assessment of building’s life cycle ⁴. -- Data source: the most recent version of Ökobau.dat or from EPDs (type III in accordance with EN 15804, ISO 14025); data not externally verified according to EN 15804 can be used only under specific conditions |
| Optimisation based on life cycle assessment | Consideration (implementation and comparison) of alternatives with life cycle assessment calculations and optimization | Descriptive and quantitative (determination of the impacts of significant alternative decisions, etc.) | +EPDs: accordance with EN 15804 and ISO 14025. |
| Evaluation of the building’s environmental impact | Evaluation of complete building’s life cycle assessment results, on the basis of comparison values | Mainly quantitative (comparison of weighted values of environmental impacts for the building with various values – limit and reference values, etc.) | |

As a principle, at the planning stage, the calculation method can be freely chosen, as long as the relative requirements are met [21].

⁴ Standard DIN 276 is referred to as well, concerning the organization and listing of building components included in the analysis.
As explained further in the following, the selection of products verified by EPDs is evaluated in the context of the factors listed in Table 5. For reasons of uniformity throughout the paper, the standards and demands for EPDs are presented in Table 5.

It is noted that “ENV1.1. Building life cycle assessment” includes, apart from the factors listed in Table 5, other indicators as well; building materials’ life cycle-related CO₂ emissions are involved in the assessment of one of them. In the context of the 3rd factor listed in Table 5, the environmental impacts are expressed as an average annual index (Environmental Impact Potential–EIP), in which the contribution of the material’s production stage is also considered. This index, in which the impacts of all of the building life cycle stages are compiled, is expressed and calculated on the basis of very well defined and analytically described information. This quantity (EIP) can be calculated for every environmental impact indicator assessed in the context of the method (i.e., GWP, ODP etc.). Reference values for this index (EIP), as well as an approach for the derivation of limit and target values, are provided in the context of the DGNB method, forming this way a scale of assessment of the respective calculated scores for the examined building. The final assessment is based on the weighted sum of the values derived for the separate impact indicators (the relative weights are predefined by the method).

The EPDs (type III) have a significant position in the LCA framework of DGNB method; they are mentioned as verified sources of various types and scales of data regarding the building materials and products (e.g., for products’ service lives/use periods’ duration, environmental impacts).

3.5. HQE

The building materials’ and products’ environmental impacts play a distinct role in the methodological approach to buildings’ environmental performance of HQE as well. Specifically, in the context of the examined version of this method [22], the relative issues are examined in the context of the sub-target “2.3. Choosing construction products in order to limit the environmental impact of the building” classified under the target “Components”. The relative information is presented in Table 6.

Table 6. LCA-related parameters in the examined version of HQE International.

| Examined factor | Thematic core of the related criteria/indicators | Type of conditions and requirements included in the criteria/indicators | Standards for LCA and EPDs & appropriate / proposed LCA tools or/and databases |
|-----------------|-------------------------------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Awareness of the environmental impacts of the products used in the building | Determination of building materials and products’ impacts in accordance with specific standards | Quantitative and descriptive (percentage and category of the products with determined impact, etc.) | •LCA: -- environmental impacts according to standard PR-EN 15804 or to an equivalent compatible standard (at a minimum derived from standard ISO 21930), -- study of scenarios according to prEN 15978 or international standard ISO 21931; calculations can be made with the use of various tools (ELODIE software, TEAM software, a summary table provided by HQE, etc.5). •EPDs are mentioned as the preferred means for gathering the required data; if not possible, other types of labels can be used under conditions. |
| Consideration of the environmental impact of the construction products in the context of their selection process | Examination of different scenarios for the products and decision-making taking into account the results | Quantitative and descriptive (examination of various numbers scenarios for different types of products, etc.) |
| Minimisation of materials’ and products’ emissions of CO₂ that are related to site procurement⁶ | Definition of transport strategies of materials, prioritising the limitation of CO₂ emissions | Descriptive and quantitative |
| Use of materials trapping CO₂⁷ | Use of specific volume of certified wood | Mainly quantitative |

⁶The information about the permitted calculation tools are provided in [22].

⁷Relatively indirect relationship with the core of LCA.
For each one of the factors tabulated in table 6, a well-defined assessment scale is used (with gradually increasing demands corresponding to bigger number of awarded points). In the context of the first factor presented in table 6, the number of points awarded to the building depends on the number of products, the environmental impacts of which have been determined according to prEN 15804 or ISO 21930; as the main categories of products dealt with in this criterion are finishing and structural/road products, the assessment scale is based on the percentage of products belonging to these product categories (minimum number of products belonging to these two categories correspond to the various levels of the assessment scale) of finishing and structural/road products. The assessment score of the second factor in table 6 depends on whether the examined scenarios, which should comply with relative standards and be taken into consideration in the final decisions, for the components with known environmental impacts, are classified in both finishing and structural products or in only one of these two groups. All the issues examined in the context of “2.3. Choosing construction products in order to limit the environmental impact of the building” account for about 28% of the available points in the “Components” target.

3.6. SBTool
The considerations related to LCA of building materials and components in SBTool refer to their embodied energy and GHG emissions. In fact, the impacts are assessed both with regard to the new materials integrated in the building and relating to the potential need for maintenance/replacement. These two different phases are dealt with in separate criteria (table 7); it is noted that these criteria are potentially active within the studied scheme (i.e. they can be assigned a relative weight of 0%).

Table 7. LCA-related parameters in the examined version of SBTool.

| Examined factor | Thematic core of the related criteria/indicators | Type of conditions and requirements included in the criteria/indicators | Standards for LCA and EPDs & appropriate / proposed LCA tools or/and databases |
|-----------------|-----------------------------------------------|---------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Embodied non-renewable energy in construction materials | Embodied non-renewable energy in original construction materials | Quantitative (comparison of annual GJ/m² for the studied building with the one of the reference building) | •LCA: relative calculations can be performed with the use of “an acceptable LCA method” [24]; alternatively, the results can be derived with the use of a spreadsheet-based calculation tool embedded in the method’s computational tool. |
| GHG emissions related to energy embodied in construction materials | GHG emissions from energy embodied in original construction materials | Quantitative (as previously) | |
| | GHG emissions from energy embodied in construction materials used for maintenance or replacement(s) | Quantitative (as previously) | |

The first factor of table 7 is assessed under the performance category “B1. Total Life Cycle Non-Renewable Energy”, which belongs to the second performance Issue of the method’s structure (“B. Energy and Resource Consumption”). The assessment criteria are the first two ones listed in the second column of table 7. Accordingly, the following criteria, used for the assessment of the second factor, are constituent parts of the performance category “C1. Greenhouse Gas Emissions” belonging
to the performance issue “C. Environmental Loadings”. The calculation of the values forming the assessment scale (benchmarks for various levels of performance, including the impacts related both to construction and to transportation) for each one of those criteria can be performed with the use of a simplified spreadsheet-based tool, which is included in the worksheets constituting SBTool. The inputs for these calculations include reference- and best-practice values for various building uses. It is noted that the calculation of the emissions on the basis of primary energy embodied in the materials requires as input the electricity power generation base load mix and the coefficients for estimating the emissions resulting from the combustion of each component of this mix; these values are directly input to reflect the local conditions. At this point it is noted that other parameters related to the impact of building materials and products (however, assessed on a basis other than LCA results), including the reuse of existing building materials and structures, the efficiency of building materials, etc., are taken into consideration in the context of the assessment process.

There is no explicit reference regarding EPDs in the spreadsheet-based computational tool of the method [23].

3.7. Level(s)
The importance of life cycle analysis and assessment is greatly highlighted in the context of Level(s). LCA parameters demonstrated in table 8 are found in the following macro-objectives: “Greenhouse gas emissions along a building life cycle” and “Resource efficient and circular material life cycles”.

The consideration, by the involved professionals, of particular environmental impacts (and, especially, the global warming potential) that are the outcome of the whole life cycle of the building, is the main goal of the examined factors. As already mentioned, there are three levels for the evaluation of every examined issue. Instructions are given in the context of the first level for the calculation of the environmental impacts and simplified paths are suggested as alternatives (LCA performed in defined life cycle stages). The analysis is conducted without quality demands for the used datasets. At the second level, the results of the life cycle analysis are compared to those of a reference building. This means that the LCA databases that are used in both cases must be compatible. Regarding the third level, the aim of the life cycle assessment is the adoption of measures for the construction of a building with reduced environmental impacts and hence LCA is performed in preliminary stages. Therefore, the quality of the chosen database is a matter of great importance and is strictly evaluated.

| Examined factor                      | Type of conditions and requirements included in the criteria/indicators | Standards for LCA and EPDs & appropriate / proposed LCA tools or/databases |
|--------------------------------------|-------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Life cycle global warming potential  | Estimation of GHG emissions resulting from every life cycle stage       | • recommended carbon footprint databases are Carbon Footprint Ltd and CarbonScopeDataTM |
|                                      | Descriptive and quantitative (calculation and recording of kg CO₂ eq/m²/yr, etc.) | • LCA:-- Databases: Bauteil katalog, Ecoinvent, GaBi and ELCD are suggested. |
| Cradle to grave life cycle assessment| Estimation of certain building’s life cycle effects on the environment  | -- Tools: some of the LCA tools referred to are GaBI, SimaPro, OpenLCA, BEES, ATHENA, ELODIE and SBTool. |
|                                      | Descriptive and quantitative (guidance for performing life cycle assessment, etc.) | • EPDs must conform to EN 15804. |

4. Discussion and conclusions
The preceding analysis outlined a picture of the integration of LCA-related parameters into the structure of well-known systems for buildings’ environmental performance assessment. Via this
analysis, similarities and differences among the adopted approaches in the examined methods can be detected.

A first conclusion that can be derived is that parameters of this nature and content are included in all the examined systems and, therefore, can be considered to play an important role in the context of a holistic approach to buildings’ environmental performance. Of course, the realisation of this inclusion varies among the environmental performance assessment methods (examination as parts of criteria, as autonomous criteria or indirect consideration in the context of other indicators).

Regarding the way the life cycle assessments and their results are taken into consideration in the points awarding structure of each system, the noted approaches range from the awareness and the consideration of such data for the selected materials and components to the comparison of these data with reference values (i.e., standard/reference building, etc.) and the examination of various scenarios.

All the examined methods include references to the use of appropriate databases (at least as a principle) and tools as sources for LCA data and as means for the conduction, where relative, of the analyses respectively. Differentiations among the examined methods can be detected also regarding this issue: for example, in BREEAM, apart from the indication of a specific database, a tool is provided for the examination of the appropriateness of any other database/method regarding LCA, while in other systems reference is made to specific LCA databases/methods or/and to the conformity with relative standards for such analyses. Tiered requirements are established for the quality of the database in Level(s), depending on the level of the analysis (it is also noted that an increased number of databases and tools of different scope can be used in the context of this framework).

Regarding the inclusion of EPDs among the examined elements, it is noted that their presence and use, either a source of LCA data or a fact itself, is evaluated in several of the assessment systems under study; their conformity to specific standards (common to a large degree among the studied methods) is also pointed out.

The review results presented in the previous sections indicate the explicit contribution of LCA-related parameters to buildings’ environmental profiles, at least as this contribution is perceived and materialised in widely used methods and in a common European framework under trial for the assessment of these profiles.

5. References
[1] Ng S T, Chen Y and Wong J M W 2013 Variability of building environmental assessment tools on evaluating carbon emissions Environ. Impact Asses. Rev. 38 131-41
[2] Ding G K C 2008 Sustainable construction—The role of environmental assessment tools J. Environ. Manage. 86 451-64
[3] Wei W, Ramalho O and Mandin C 2015 Indoor air quality requirements in green building certifications Build. Environ. 92 10-9
[4] Lee W L 2012 Benchmarking energy use of building environmental assessment schemes Energ. Build. 45 326-34
[5] Illankoon J M C S, Tam V W Y, Le K N and Shen L 2017 Key credit criteria among international green building rating tools J. Clean. Prod. 164 209-20
[6] Mattoni B, Guattari C, Evangelisti L, Bisegna F, Gori P and Asdrubali F 2018 Critical review and methodological approach to evaluate the differences among international green building rating tools Renew. Sust. Energ. Rev. 82 Part 1 950-60
[7] Krizmane M, Slihte S and Borodinec A 2016 Key criteria across existing sustainable building rating tools Energ. Procedia 96 94-9
[8] Awadh O 2017 Sustainability and green building rating systems: LEED, BREEAM, GSAS and Estidama critical analysis J. Build. Eng. 11 25-9
[9] Sev A 2011 A comparative analysis of building environmental assessment tools and suggestions for regional adaptations Civ. Eng. Environ. Syst. 28 231-45
[10] Cole R J 2005 Building environmental assessment methods: redefining intentions and roles Build. Res. Inf. 33 455-67
[11] Sinou M and Kyvelou S 2006 Present and future of building performance assessment tools *Manag. Environ. Qual.* **17** 570-86

[12] Bernardi E, Carlucci S, Cornaro C and Bohne R 2017 An analysis of the most adopted rating systems for assessing the environmental impact of buildings *Sustainability* **9** 1226

[13] Park J, Yoon J and Kim K H 2017 Critical review of the material criteria of building sustainability assessment tools *Sustainability* **9** 186

[14] Bueno C, Rossignolo J A and Ometto A R 2013 Life cycle assessment and the environmental certification systems of buildings *Gestão & Tecnologia de Projetos (Des. Manag. Technol.)* **1** 7-18

[15] Berardi U and Tortorici G 2011 Comparison of sustainability rating systems for buildings and evaluation of trends *Proc. of SB11 Helsinki World Sustainable Building Confer.* (18th to 21st October 2011 Helsinki ) (available at: http://www.irbnet.de/daten/iconda/CIB_DC23179.pdf)

[16] Giarma C, Tsikaloudaki K and Aravantinos D 2017 Daylighting and visual comfort in buildings’ environmental performance assessment tools: a critical review *Procedia Environ. Sci.* **38** 522-29

[17] Savvastaki-Sevastaki D, Ktistaki E and Giarma C 2018 Energy behaviour of buildings of the tertiary sector in the context of their environmental performance assessment tools: comparative review and analysis (in greek) *Proc. of 11th national conf. on renewable energy sources (14th to 16th October 2018 Thessaloniki)* vol. 3 (Thessaloniki: Institute of Solar Technology) pp 227-38 (available at: https://solarinstitute.gr/praktika-synetdron/)

[18] BRE Global Ltd 2017 BREEAM International New Construction 2016 (SD233– Issue: 2.0)

[19] U.S. Green Building Council 2018 LEED v4 for Building Design and Construction (2018 update)

[20] Japan’s Institute for Building Environment and Energy Conservation 2014 CASBEE for Building (New Construction: 2014 edition)

[21] DGNB 2018 DGNB system (2018 version) - https://www.dgnbsystem.de/en/system/version2018/

[22] CERWAY 2016 Assessment scheme for the environmental performance of non-residential building under construction - HQE™ certified by Cerway (2016 version)

[23] iiSBE 2015 SBTool_2015_Generic_MAX_Dsn_20jun15

[24] Larsson N 2015 SBTool 2015 – overview (available at: http://iisbe.org/system/files/SBTool%20Overview%2004May15.pdf)

[25] Dodd N, Cordella M, Traverso M and Donatello S 2017 Level(s) EU Framework of Building Indicators Part 1 and 2: Introduction to Level(s) and how it works (Beta v1.0) EUR 28899 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-76914-6, JRC109285

[26] Dodd N, Cordella M, Traverso M and Donatello S 2017 Level(s) EU Framework of Building Indicators Part 3: How to make performance using Level(s) (Beta v1.0) EUR 28898 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-76907-8, JRC109286

[27] Bitsiou E 2018 The inclusion and consideration of parameters related to life cycle and life cycle analysis of building materials and elements in the context of methods for the assessment of buildings’ environmental performance (in greek) Diploma Thesis, Department of Civil Engineering, Aristotle University of Thessaloniki

[28] Cole R J and Larsson N K 1999 GBC’98 and GBTool: background *Build. Res. Inf.* **27** 221-29

[29] Japan’s Institute for Building Environment and Energy Conservation 2014 Assessment Software Version: CASBEEBD_NC_2014 (v2.1) (available at: http://www.ibec.or.jp/CASBEE/english/downloadE.htm)