





## Article

# Recommendations for Developing a BIM for the Purpose of LCA in Green Building Certifications

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**Abstract:** Building information modeling (BIM) and life cycle assessment (LCA) are two methods that can be helpful when designing buildings with lower environmental impacts. One of the most significant examples of environmental impact assessments in construction is green building certification. Certified buildings have improved performance and greater asset value. In this study, four certification systems were investigated for their potential interconnections with BIM and LCA. The main tasks were (1) to review a BIM-based workflow, (2) assess its usage as an input for the LCA within green certifications, and (3) provide suggestions for developing building models. Building models can be helpful during the design process, but the best results are expected when the specifically described steps are followed. These suggestions aim at improving building models in terms of their usage for green building certifications and particularly for LCA. All the investigated results were clarified and adjusted using a model of a recently finished building in Zug. As reference tools, One Click LCA and a manual process were selected. The outcomes were aligned with those of other studies and confirmed the necessity of good data and management quality for building projects.

**Keywords:** BIM (building information modeling); LCA (life cycle assessment); green building certification; BREEAM (building research establishment environmental assessment method); LEED (leadership in energy and environmental design); DGNB (Deutsche gesellschaft für nachhaltiges bauen); SBToolCZ (sustainable building tool Czech Republic); one click LCA

## 1. Introduction

Researchers, such as Smil [1], and organizations, such as the Intergovernmental Panel on Climate Change (IPCC) [2] and the United Nations Environment Programme (UNEP) [3] have suggested that in the following decades, mankind will face large challenges in climate change and energy usage. Various studies have confirmed that the construction sector has a significant negative impact on the global environment, with approximately 40% raw material consumption and 50% global greenhouse gas emissions [4–6].

A significant proportion of the environmental impacts of the construction sector are allocated to buildings. At the same time, this segment has a significant potential for massive savings [7,8]. The most commonly used method to assess the environmental impact of buildings is the life cycle assessment (LCA). Thanks to its complexity and flexibility, LCA can also be used for complex products, such as buildings [9]. The current challenges and possible future outlook of LCA were well described by Fauzi et al. [10]. However, this application requires a great deal of time, high levels of expertise, and a large amount of data, which are sometimes difficult to access. To make the LCA of buildings

more obtainable for stakeholders, many tools have been developed to simplify, unify, and speed up the process. Overviews of such tools can be found in [9,11].

Along with the LCA, other effective tools that can improve the building design process are needed. Recent digitalization has significantly changed the traditional building design process through building information modeling (BIM). Studies have shown that combining an LCA-BIM workflow can significantly reduce the time and effort needed for proper building evaluation [6,8].

When the BIM of a building project is well established according to the common international standards (i.e., PAS 1192 [12], which was recently superseded by ISO 19650-1:2018 [13] and the Employer's Information Requirements (EIR) [14]), and when BIM execution plans (BEPs) [15–17] are developed by all the influenced stakeholders, the whole project will be very positively impacted (improved project management, precise bills of quantities (BoQs), etc.) [18]. However, integrating a full life cycle assessment (LCA) process into this workflow entails significant expertise and a high degree of uncertainty [19,20]. Implementable workflows have been already developed for the early stages of the design process [21]. A parametric design can also be employed in the building design process, as described, e.g., by Kiss [22] and Wiberg [23]. Even though all of the referenced outcomes are relevant and valuable for future development, this paper is primarily focused on the market approach. None of the presented solutions fit into the competitive world of the construction market, due to the great importance of speed and simplification.

For this purpose, a wide variety of green building certification systems have been developed. These systems provide building evaluations that are easily understandable for the wide public sector, and they combine several aspects of sustainability. However, these certifications also include a simplified LCA approach. The demanded scopes and boundaries of the LCA differ significantly among various certification schemes and are defined in Sections 2.3–Section 2.6. In this paper, four different evaluation methods used in the Czech construction market are selected for further investigation.

There is a large body of literature describing the implementation of BIM and environmental LCA into a project's processes [24–28]. However, few studies [25,27] have focused on a specifically relevant workflow. The most recent systematic literature review of integrating BIM and LCA was published by Obrecht et al. [29], which summarizes the topic from various perspectives and gives structured overview.

Another aspect of BIM is energy modeling (in some references, this is described as the building energy model or BEM), which is very helpful in the design process as well as in the operational phase of building. A comprehensive outlook of this field with many references is provided by Farzaneg et al. [26]. Another overview was produced by Ruben et al., who described a similar approach for the evaluation of office buildings in Western Europe [30]. However, this part of BIM was not included in this article.

This paper seeks to create an overview of the current market situation and help BIM users to prepare their models for the purpose of evaluation according to the needed inputs of various certification systems. The aim of this paper is to create a list of advice for developing BIM models that are “LCA-ready”.

## 2. Methods

### 2.1. Method Overview

After selecting the certification scheme, the common process of building certification along with the BIM workflow is as follows:

1. Export data from the BIM model in the form of BoQ into the LCA model (via an online platform or MS Excel spreadsheet).
2. Cluster the data from BoQ into categories within the LCA model according to the rules of the selected certification system. In this process, it is helpful when the model contains a classification system (e.g., Uniclass 2 and CoClass) for possible automatization.
3. Evaluate the building properties according to the selected certification system.

4. Further optimize the building design.
5. Repeat the loop until the results are satisfactory.

This process was simulated using a case study (described in Section 2.8) using four selected certification schemes to determine a set of recommendations that can be easily implemented in the previously mentioned stakeholder agreements (EIR and BEP).

In the case study, we exported BoQ data out of the BIM using the One Click LCA software for the BREEAM (Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design), and DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) evaluations and used an Excel spreadsheet for the SBToolCZ evaluation. The outputs from both workflows were similar. The method used in this paper is shown in Figure 1.

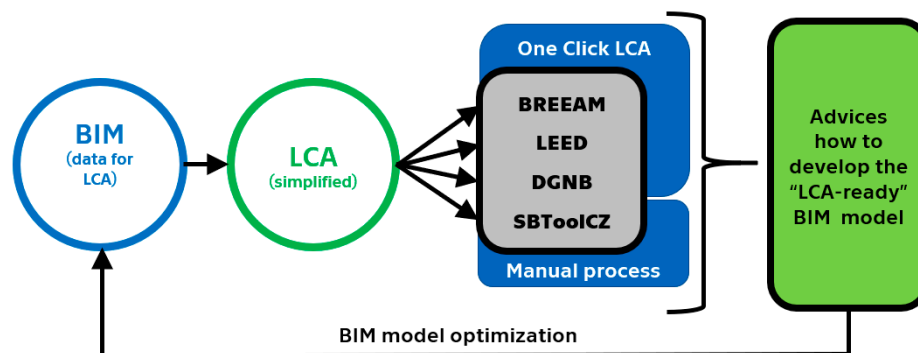


Figure 1. Workflow described in the paper.

## 2.2. Selected Certification Systems

BREEAM (UK) [31] and LEED (USA) [32], with 571,115 and 95,000 certified buildings, respectively, were selected for this study as the leading certification systems with the most use-cases globally. The third certification scheme selected for the study was the German DGNB [33], which is used in several European markets. The final investigated certification system was SBToolCZ [34] (CZ). This system was developed for the specific needs of the Czech market and has become a standard for the public building sector in the country. It was developed at the present author's university, the Czech Technical University in Prague, and was thus included in the selection.

During this research, the authors determined that the local data from the Czech Republic follow global trends. According to the Czech Green Building Council (CZGBC) [35] and official statistics, 130 [36] and 57 [37] buildings, respectively, are currently certified in the Czech Republic. Therefore, the research done for this paper has importance for the local market as well.

The following sections provide descriptions of each certification system as follows:

1. Certification scheme overview;
2. Relation to LCA;
3. BIM specification.

## 2.3. BREEAM

### 2.3.1. Overview

BREEAM (Building Research Establishment Environmental Assessment Method) is a third-party certification for the assessment of the sustainability performance of individual buildings, communities, and infrastructure projects. This assessment can take place during various stages of a project's life cycle, from design and construction through to operation and refurbishment. The BREEAM certification process involves the assessment of a project by qualified and licensed BREEAM assessors and by the certification body BRE (Building Research Establishment). A BREEAM certificate may be issued

with several ratings (Pass, Good, Very Good, Excellent, or Outstanding) according to the percentage score achieved by the project. The maximum number of points available depends on the function and assessment type of a building, to which weighting is applied and the final percentage score is calculated. An additional 1% is available for each “innovation credit” (up to maximum of 10%, with the total BREEAM score capped at 100%) [38].

### 2.3.2. Relation to LCA

The BREEAM International New Construction 2016 scheme is a performance-based assessment method and certification scheme for various types of new buildings. This scheme can be further divided into several assessment types, particularly for nonresidential projects: fully fitted, shell and core, and shell only [38].

Within the BREEAM International New Construction 2016 scheme, the Mat 01 Life cycle impacts issue recognizes and encourages the use of robust and appropriate life cycle assessment tools over the full life cycle of the building, with a reference study period of at least 60 years.

At present, this issue is concerned with the use of the LCA on the project and the robustness of the method or tools used; BREEAM does not seek to benchmark the resulting performance. Performance benchmarking will, however, likely be included in the following versions of the scheme as LCA matures. To calculate the number of credits received by the project, the Mat 01 calculator is used. The Mat 01 calculator scores points based on the rigor of the LCA in terms of the quality of the assessment tool or the method and data and the scope (of building elements) included in the assessment. The software through which the LCA is performed must be recognized by BREEAM; examples of such software include the BRE Green Guide, eTool LCD, and One Click LCA [39].

### 2.3.3. BIM Specification

As stated above, the number of points is determined using the Mat 01 calculator (Excel spreadsheet accessible by the BREEAM assessor and BREEAM AP certified persons), among others, according to the environmental impact categories calculated by the LCA, with embodied carbon as the mandatory indicator, along with embodied water or waste processing and any two additional indicators. This score is further determined based on the building elements included in the analysis. Several building element groups are mandatory within the LCA:

- External walls (envelopes, structures, and finishes),
- External windows (including roof windows),
- Internal floor finishes (including access floors),
- Upper floors (including horizontal structures),
- Internal walls and partitions,
- Roof (including coverings).

Various types of building elements (fabric, building services, and landscaping) are attached to a point factor based on their importance, but these need to be included in the assessment only if the project aims to achieve a high number of credits.

Apart from the mandatory building elements listed above, the highest point factor (2.00) is attached to the following:

- Foundations (including excavation);
- Structural frame (vertical);
- Heat source, space heating, air conditioning, and ventilation.

A table of all the required parameters is provided in Appendix A.

## 2.4. LEED

### 2.4.1. Overview

LEED (Leadership in Energy and Environmental Design) is a green building rating system developed by the U.S. Green Building Council. The current version used in the industry is LEED v4, launched in November 2013. Projects aspiring to LEED certification can reach levels of Certified, Silver, Gold, or Platinum, depending on the number of points received. The maximum number of available points is 110.

### 2.4.2. Relationship to LCA

The LEED v4 Building Design and Construction (BD+C) includes a new credit called Building Life Cycle Impact Reduction. One of the options available to obtain this credit is Option 4: Whole-Building Life-Cycle Assessment (LCA). This option is worth three points, with the possibility of one extra point.

The LEED credit requires one to improve the building life cycle impacts by 10% compared to a baseline building, which must be of comparable size, function, orientation, and location; the reference study period of both the baseline building and the proposed building must be at least 60 years. The LCA must be calculated for six listed environmental impact categories: global warming potential (GWP), the depletion of the stratospheric ozone layer, the acidification of land and water sources, eutrophication, the formation of tropospheric ozone, and the depletion of nonrenewable energy sources. To obtain the LEED points for this credit, three of these categories, including GWP, must demonstrate a minimum of a 10% reduction compared to the baseline. At the same time, no category of impacts may increase by more than 5% compared to the baseline. An additional point is awarded for displaying a 10% reduction in all six impact categories.

The LCA in LEED is a cradle-to-grave quantification of the environmental impacts of a building or a portion of a building, considering the entire value chain using data compliant with the ISO 14040/44 [40] standard. For European projects, the EN standard 15978 [41] may be used as a framework for the life cycle assessment combined with EPD (environmental product declaration) data. The used data must comply with ISO 14044, which is typically ensured by LCA software that conforms to LEED v4's requirements.

### 2.4.3. BIM Specification

When calculating the LCA for LEED certification, the analysis's material scope must be the same for the baseline and the proposed building. The LCA analysis should include the following building elements:

- Standard and special foundations;
- Slab on grade;
- Basement walls;
- Columns;
- Floor construction;
- Roof construction;
- Exterior and semi-exterior walls from cladding to finishing;
- Exterior windows and doors;
- Roof coverings and openings;
- Load-bearing partitions;
- Stair construction;
- Parking structures.

LEED v4 excludes the following elements from the analysis: electrical and mechanical equipment and controls, plumbing fixtures, fire detection and alarm system fixtures, elevators and conveying systems, excavation and other site development, and parking lots.

A table of all the required parameters is provided in Appendix A.

## 2.5. DGNB

### 2.5.1. Overview

DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) is an international certification system for sustainable buildings that assesses buildings using 50 criteria within the following areas: environmental quality, economic quality, sociocultural and functional quality, technology, process workflow, and site. This is a very flexible certification system that can be adapted to different countries and different types of buildings. This assessment covers the entire life cycle of a building.

### 2.5.2. Relation to LCA

The ecological criteria for the DGNB include several groups: building life cycle assessment, local environmental impact, sustainable resource extraction, potable water demand and waste water volume, land use, and biodiversity at the site. This paper deals only with the criteria belonging to the Building Life Cycle Assessment (ENV. 1.1.) group, which has a relatively significant weight (8% [42]) when assessing office buildings. The assessed criteria are as follows:

1. Integration of life cycle assessments into the planning process;
2. Life cycle assessment optimization during the planning process;
3. Comparison of the LCA results with benchmarks (the most weighted criterion);
4. Potential to achieve climate neutrality;
5. Circular economy;
6. Halogenated hydrocarbons in refrigerants.

The complete procedure can also be used. In that case, the rules for neglecting some elements are significantly stricter, but there is no need to multiply the resulting impacts by a factor of 1.2.

Appendix A of the document [42] lists the groups of materials and components classified in accordance with DIN 276 [43], indicating the relevance for each life cycle stage counted in the DGNB evaluation for each group.

Specific data (EPD) are preferred. If generic data are used, they must be from the latest Ökobau.dat database. The assessed indicators are global warming potential (GWP), ozone depletion potential (ODP), photochemical ozone creation potential (POCP), acidification potential (AP), eutrophication potential (EP), nonrenewable primary energy demand (PE<sub>nr</sub>), total primary energy demand (PE<sub>tot</sub>), proportion of renewable primary energy, abiotic basic resource depletion potential (ADP<sub>elements</sub>), and the net use of fresh water (FW). For conversion to the overall score, the individual indicators are weighted using weighting factors; the highest weight has a GWP of 40%.

The LCA procedure is clearly described by the DGNB in [34]. The basic requirements that must be met will be described in the following sections. The functional equivalent is an entire building without external installations. The reference study period for new office buildings is 50 years. The cradle-to-gate phase (A1–A3), maintenance and replacement phase (B2 and B4), energy and water consumption during the operation of the building (B6 and B7), and end-of-life phases of waste recycling (C3), disposal (C4), and potential for reuse (D) are considered in the calculation. In the maintenance and replacement phase, only the manufacture and disposal of the replaced elements are considered. A complete procedure can also be used. In this case, the rules for neglecting some elements are significantly stricter, but there is no need to multiply the resulting impacts by a factor of 1.2 [42,43].

### 2.5.3. BIM Specification

At least the following material groups (cost groups 300 and 400 in accordance with DIN 276 [35]) must be included to calculate the impacts at the production stage and, consequently, the impacts associated with disposal. The simplified procedure includes the following [42]:

- External walls (including doors and windows) and basement walls,
- Roofs;
- Internal floors and ceilings (including floor structures and floor coverings and coatings);
- Ground-level floor (including floor construction and floor coverings and coatings, as well as floors above open spaces);
- Foundations;
- Internal walls and doors (including coatings and internal columns);
- Heating and cooling systems and air conditioning systems;
- Other building installations (e.g., photovoltaic systems or solar collectors);
- In individual cases: user equipment with considerable energy consumption in the use phase.

To determine the quantities of materials and components, a number of rules are laid down in this simplified procedure, which must be observed and must allow some materials and elements to be neglected. When the simplified calculation method is used, the indicator results for the production phase, maintenance, and replacement, as well as those for end-of-life, must be multiplied by a factor of 1.2.

A table of all required parameters is described in Appendix A.

## 2.6. SBToolCZ

### 2.6.1. Overview

SBToolCZ [44] is a certification method for sustainable buildings in the Czech Republic. The criteria are merged into three main groups: (1) environmental, (2) social, and (3) economic. Besides these groups, location is also considered as the fourth group, although it does not influence the overall evaluation. This method can be applied in the design phase of a building and may vary slightly according to the object's typology (e.g., for office buildings [45], residential building [46,47], and schools [48]). The results contain two phases: precertification and final certification. Precertification can be done only with the project documentation, and final certification is verified during the building approval process or during the full operation of the building. Then, a final certificate can be awarded.

### 2.6.2. Relation to BIM and LCA

In contrast to other certification methods, SBToolCZ does not require a separate LCA analysis. Instead, the LCA subsection is outlined based on descriptions of the individual criteria of the environmental portions of the methods. SBToolCZ is a manual way to create/perform the desired simplified LCA analysis in the Czech Republic. The first six environmental criteria describe an evaluation of the embodied and operational impacts for six environmental indicators: PEI, GWP, AP, EP, ODP, and POCP. The embodied impacts include life cycle phases (A1–A3) and a partial phase (B4) as the service life of each material is considered for replacement. The operational impact corresponds with phase B6. These criteria have benchmarks that are set for these six indicators. The method for office buildings is currently the oldest; therefore, some parts of the assessment were omitted due to insufficient data: The embodied impact of EP and the operational impact of OPD and POCP, for example, were not evaluated. This method is expected to be updated.

The criteria for phases (A4) and (D) assess the weights of materials produced and imported regionally (up to 100 km), respectively, which defines the amount of renewable or recyclable material. SBToolCZ also evaluates water consumption

If the building is designed as a shell and core, the construction elements and materials that are not yet known are not included in the calculations for precertification. The same approach applies to buildings with standard designs. The calculations are clarified during the process of final certification after the process of approval.

Currently, the SBToolCZ is under revision, and a semiautomatic BIM-based workflow has been developed by the authors of this paper. The developed tool will be a web-based application. The workflow is shown in Figure 2.

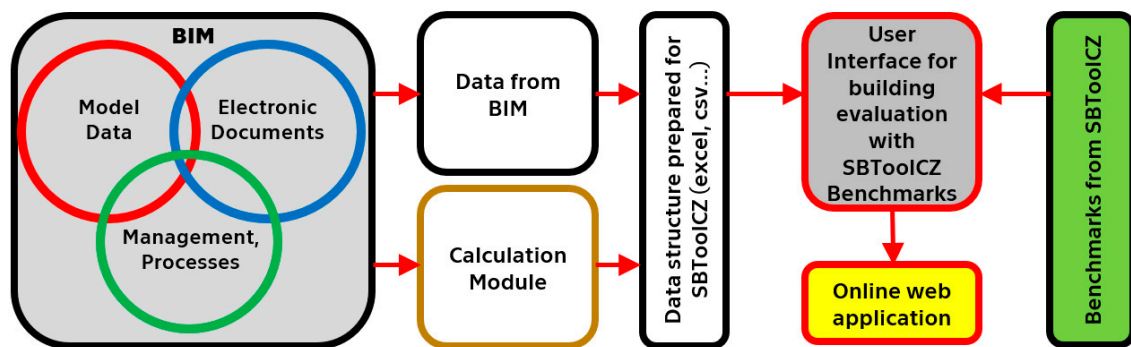


Figure 2. Building information modeling (BIM) based workflow of the developed tool.

### 2.6.3. BIM Specification

To calculate the embodied impact, the quantities of these construction elements must be listed:

- Foundation;
- Waterproofing layers;
- Compacted fill and backfill material (imported from places outside the building);
- Vertical and horizontal construction elements, including overhanging structures;
- Roof construction;
- Roof deck;
- Staircase;
- Railing;
- Internal partitions;
- Nonbearing cladding;
- Finishes;
- Final floor covering;
- Windows and doors;
- Thermal and acoustic insulation.

Other elements of construction are not included in the calculations, such as small finishing elements (lathes, metal elements, handles, and others) and building service systems (including electric wiring).

A table of all the required parameters is provided in Appendix A.

### 2.7. LCA Platform

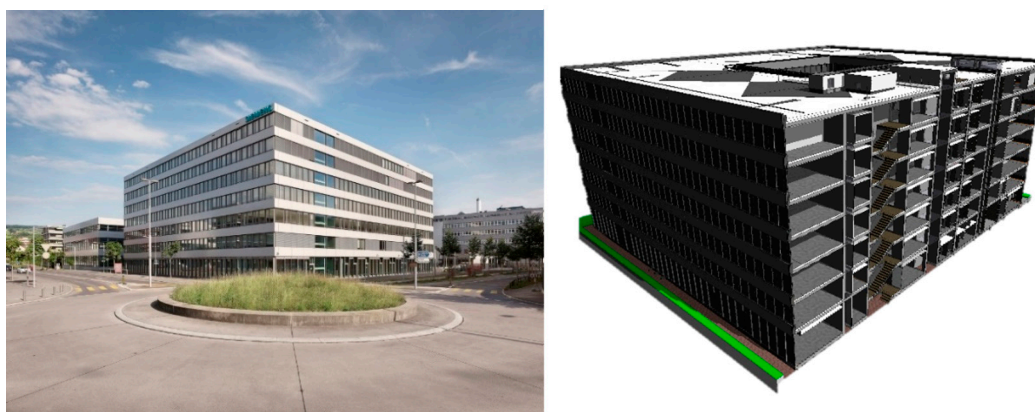
Currently, there are two main platforms usable for certification systems that are available on the market that can incorporate BIM data and LCA: Tally [49] (USA) and One Click LCA [50] (FIN). Both platforms are equally capable for LCA analyses. One Click LCA was selected due to its direct connection with the international certification systems used in this paper. For SBToolCZ, a manual process of data extraction was used.

## 2.8. Case Study

The methods described in previous sections were applied to compare different approaches. For the case study, a Siemens Office Building in Zug, Switzerland was used. This building was finished in 2018 (fully operational from April 2019) as the new headquarters of Siemens Building Technologies and Smart Infrastructure divisions. This building has been published in various resources [51–53]. With a gross floor area (GFA) of 33,000 sqm spanning 7 floors (plus 3 underground), this building can accommodate around 500 office workers. The project budget was 250 million Swiss francs (CHF). The same case study project was investigated by Kiamili et al. [54].

The Siemens company has committed to attaining carbon neutrality by 2030 [55], and this new building is one of the leading projects intended to fulfill this ambitious target. Notably, in this project developed by Siemens, the BIM was applied in one of its first use-cases. However, it is clear that the BIM will soon be a new worldwide standard [56]. Since one of the present authors works for Siemens Real Estate, this study area provided the opportunity to investigate a model of a real building.

The model does not contain any classification system, so the whole process had to be done manually. The model was developed in Autodesk Revit 2019. It was not edited for the purposes of this paper. We only exported BoQ data out of the model with the One Click LCA software for the BREAM, LEED, and DGNB evaluations and with the Excel spreadsheet for the SBToolCZ evaluations. The building as well as model are shown in Figure 3.



**Figure 3.** Building in Zug: current status and BIM model. (<https://press.siemens.com/global/en/feature/inauguration-new-siemens-campus-zug>).

## 3. Results and Outcomes

### 3.1. BREEAM, LEED, DGNB: The One Click LCA Process

All these certification systems are supported by the One Click LCA evaluation software. In this online platform, the user selects the certification method and the building type, country, and other boundary conditions. Then, it is possible to import data taken from the BIM (e.g., from Autodesk Revit). The platform then returns instant feedback on the model quality and granularity.

Materials with understandable naming conventions are automatically mapped with the national LCA databases. Materials that are not recognized by their name cannot be mapped automatically, and manual (time-consuming) mapping is needed. This process is intended to be done by an LCA expert.

The provided BIM model in our study contained many details of the design and project documentation. In general, the overall quality was high. Despite this fact, analysis via the One Click LCA showed that, for the evaluation processes of all green building certification types, many details and information were still missing:

- 11,860 rows that represent the model elements were investigated, and the following problems were found:
  - 7 implausible thickness values (0.06% of the model)
  - 113 generic definitions (0.95% of the model)
  - 128 geometry errors (1.08% of the model)
  - 51 out of scope, i.e., (not relevant for the chosen LCA tool: 0.43% of the model)
- The whole model was segmented into 201 materials:
  - 63 materials (81.1% of volume) were automatically identified
  - 138 materials (18.9% of the volume) were not automatically identified
- The process of “cleaning” the model is time-consuming. The workflow contains the following:
  - Checking geometry and resolving collisions
  - Fixing model granularity
  - Parsing undefined materials

The estimated time for resolving the aforementioned problems depends on the model shape and its overall quality. In this case study, the whole process took approximately 20 working hours. It is not possible to follow this process in practice because the project owner (client) would not edit the model. The only correct way to follow the process is for the project designer to create the model according to the client’s needs based on the LCA analysis. This process requires a proper project definition from the owner and a capable project architect who is able to fulfill all the client’s needs. This demonstrates the need for an EIR and BEP where all the details are described.

### 3.2. SBToolCZ: Manual Process

Software for the LCA according to SBToolCZ is still under development. Therefore, the BoQ was manually generated from the BIM, and its items were paired manually with the environmental database. The model was exported into a spreadsheet containing 12,691 rows, which represent the model elements, and a generated list grouped into 128 materials.

The whole process of mapping materials with the LCA database was also manual and, therefore, very time consuming (approximately 20 working hours). The following problems were found that pertain to the materials in the BoQ not being described enough:

- In 3% of elements, the area was missing.
- In 11% of elements, the volume was missing.
- In 51% of elements, the density was missing.

All the problems with parsing materials from the BoQ with data from the environmental database also had to be fixed in the model manually, which created extra work. This process is even more manual and complicated than the previously used process in Section 3.1 with One Click LCA.

This process can be followed in practice since the material parsing is done externally from the BIM model. However, it is not efficient due to the need for manual work. The knowledge gained from this research was used to develop an automated workflow for the SBToolCZ.

### 3.3. Outcomes

For the purpose of this study, the provided model was a proper use-case that perfectly demonstrated the typical problems of the models that are currently produced. It is clear that BIM can be helpful for designing high-performance buildings. However, it is necessary to follow some recommendations for the model development. Experience from the case study resulted in the following suggestions:

1. Proper project and BIM management should include documents such as EIR and BEP. These documents should be implemented into the legal documents signed by the main project stakeholders.
2. The classification system (Uniclass 2, CoClass etc.) has to be used across the whole project for the most effective automatic recognition of the building elements. The decision process for selecting the correct system is crucial. The selected classification system should follow the client's and project's needs, as well as national requirements.
3. A high-quality material database with the all related information should be used (name, description, physical, thermal, and other properties). This element is important when mapping to LCA databases. Otherwise, the whole mapping workflow has to be processed manually, which requires much time and effort.

The usage of One Click LCA or a similar platform especially simplifies the evaluation process. Further, when the aforementioned recommendations for the model development are followed, the amount of time needed for evaluating relevant green building certification systems rapidly decreases with satisfactory feedback and a limited number of problems. In this case study, this method had a positive effect, increasing efficiency by around 50% (25 h). This time can be used for building optimization and ensuring better overall performance.

## 4. Discussion

### 4.1. Relation to Other Papers

Due to the high demand of LCA expertise, which has problematic applications in daily life, a simplified approach was used in this paper. In the literature, the process of comparing the full LCA with BIM-based workflows is well described (e.g., by Bueno et al. [57]). This process reveals that some degree of simplification yields satisfactory results [58], with less effort needed for a full LCA.

According to the research done for this paper, the One Click LCA is currently one of the most developed tools [59] available on the market that can be used for a simplified LCA approach. It allows one to use international green building certifications and databases, as well as BIM-based workflows, for all assessed certifications, except for the Czech SBToolCZ system, in which certifications are processed manually.

Another method of exporting BoQ out of the BIM model is to develop one's own semiautomatic workflow using a tool such as Dynamo or Grasshopper. This process is well described by Hollberg [25]. For work on projects related to daily life routines, this workflow is more efficient.

The recommendations for developing the BIM model described in Section 3.3, which was applied to the described case study, would be helpful for both workflows (i.e., the semiautomatic workflow with One Click LCA and the manual workflow with Excel). However, they could be applied only at the beginning of the building project.

In the literature, two trends are described for the BIM-LCA workflow [27]: one in the early design phase with a high degree of simplification and another more complex model with a high degree of accuracy. They proposed a method of building assessment in five different project stages. However, this valuable invention was not suitable for the case study in this paper because we sought to use a project consisting of one project phase only.

The recommendations in Section 3.3 of this paper correspond with those of another study published by Röck et al. [60], whose study concludes as follows: "(a) The organization and structure of information on buildings, as well as (b) the levels of granularity and scope for both BIM elements and LCA data, is required." This shows the importance of data and quality management on construction projects.

#### 4.2. Limitations of the Study

Different environmental databases have different structures and different levels of detail. Therefore, the required structure of the BIM model, its detail, and the information that can be obtained from it are likely to differ when using different environmental databases.

The recommendations proposed in Section 3.3 could be too generic. This is because every building project is different, and all countries have different legislations, construction practices, and norms.

One Click LCA brings together environmental data from many different sources, including various national and international databases of specific data (EPDs) but also various generic databases. The user then combines these data in the model. However, this process is considered not correct from the perspective of LCA because different methodologies are applied for developing different environmental databases. It is recommended to use data from one source and, if using multiple sources, to verify the compatibility of those sources. This means that the user must be very careful with parsing materials from the model, including materials from the database in One Click LCA.

Results may also vary according to the authoring tool used for the evaluation process. As shown in Section 2.7 “LCA Platform”, currently only a limited number of tools are available on the market. However, the BIM can be used only as a platform for BoQ, and thus a manual process of the evaluation can be used. Although this process is manual and time consuming, it is still the most common way of work as is shown in the aforementioned systematic literature review [29]. This process is possible; however, it leads to a wide range of results [61,62].

#### 5. Conclusions

This study sought to produce recommendations for developing BIM models that are more suitable for the LCA. The main condition involved usage not in an academic context but under real AEC (architecture, engineering and construction) market conditions. For this reason, green building certification systems were selected instead of a full LCA. Four certification systems already used in the Czech Republic (BREEAM, LEED, DGNB, and SBToolCZ) were selected and analyzed for their relationships to LCA and BIM.

The process was simulated based on a case study of the Siemens office building in Zug. The workflow of mapping materials from the BIM to LCA database was separated into two streams: (1) a semiautomatic workflow with One Click LCA (BREEAM, LEED, DGNB) and (2) a manual mapping (SBToolCZ). As the main result and output of this study, recommendations were provided, showing the importance of (1) EIR and BEP, as well as their implementation in legal documents; (2) the classification system and its usage within all the building models; and (3) the use of a quality material database for all the models. When these recommendations are followed, the project data quality of the BIM-LCA workflow can be significantly improved.

#### Future Work

This study showed that there is large potential for future development in this field. However, it is important to have deep knowledge in both topics of BIM and LCA. Otherwise, the results are distorted due to bad model quality or incorrect material parsing.

Subsequent steps will cover deeper research, and the steps are as follows: (1) Compile a summary of the conclusions into the methodology of developing BIM which is ready for LCA, (2) develop a web-based platform that is tailored for SBToolCZ and allows for a semiautomatic workflow (similar to the One Click LCA for another methodologies), (3) perform result clarification into different case-studies, and ultimately (4) implement learnt lessons into the Czech BIM-legislation system that is now under development.

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## Appendix A

Comparison of Certification Systems				
Evaluated aspects	BREEAM	LEED	DGNB	SBToolCZ
<b>Life cycle phases</b>				
A1–A3 - Production phase	●	●	●	●
A4 - Transport to the construction site		●		
A5 - Construction process				
B1 - Use		●		
B2 - Maintenance		●	●	
B3 - Repair		●		
B4 - Replacement	●	●	●	●
B5 - Repair	●	●		
B6 - Operational energy use	●		●	●
B7 - Operational water use	●	●	●	
C1 - Deconstruction, demolition	●	●		
C2 - Transport	●	●		
C3 - Waste processing	●	●	●	
C4 - Disposal	●	●	●	
D - Reuse, recovery, recycling	●		●	
<b>Mandatory elements to be included</b>				
Load bearing structures (walls, columns, floors, roofs)	●	●	●	●
Foundations and basement walls	●	●	●	●
Windows and doors	●	●	●	●
Non-loading walls	●	●	●	●
Other non-load bearing structures (coatings, coverings, finishes, cladding)	●	●	●	●
Building installations (heating, cooling, air-conditioning, PV panels etc.)			●	
<b>Indicators</b>				
Global warming potential	●	●	●	●
Ozone depletion potential	●	●	●	●
Photochemical ozone creation potentials	●	●	●	●
Acidification	●	●	●	●
Eutrophication potential	●	●	●	●
Primary energy, non renewable			●	●
Primary energy total			●	
Abiotic depletion potential			●	
Non- hazardous waste			●	
<b>Others</b>				
Reference study period (years)	60	min. 60	50	50
Benchmarks for LCA result			●	●
Mandatory databases or tools for LCA	●		●	
● Relevant ● Partly relevant				

**Figure A1.** Comparison of Certification Systems.

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