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Identification and comparison of LCA-BIM integration strategies

To cite this article: L Wastiels and R Decuyper 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012101

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Identification and comparison of LCA-BIM integration strategies

Wastiels L, Decuypere R

Belgian Building Research Institute (BBRI-CSTC-WTCB), Belgium

lisa.wastiels@bbri.be

Abstract. With increasing use of BIM (Building Information Modelling) in the design of construction projects, opportunities arise to integrate Life Cycle Analysis (LCA) in early design phases efficiently with minimum additional burden for the design team. Different levels of integration can be envisaged, ranging from a BOQ export (Bill Of Quantity) based on the BIM-model to import in native LCA-software, up to a real time LCA-calculation within the native design environment, giving real time feedback on design decisions, or alternatively utilizing the standardized BIM-information exchange format IFC. Based on the evaluation of existing tools, this paper focuses on the possible workflows for the integration of LCA and BIM. A comparative analysis between these different information flow structures exposes their advantages and disadvantages, depending on the design phase they are used in and the availability of generic, product-specific or manufacturer-specific LCA-data.

1. Introduction

The AEC sector (Architecture, Engineering and Construction) is going through an important digitization process, with the rocketing adoption of BIM (Building Information Modelling) in the different design and construction phases, allowing for an efficient exchange of building information between the different specialists and reuse of information in different phases. This creates opportunities to more efficiently carry out multiple analyses based on the available building information while minimizing the need for manual data entry in the discipline specific simulation tools.

At the same time, growing concerns about the environmental impact of buildings trigger a demand for thorough Life Cycle Analysis (LCA) in the design phase. However, the integration of LCA in the design process is not mainstream yet. LCA databases and tools being in full development, and there is still uncertainty on how to best align the demands from the LCA practitioner with those of the rest of the design team. Consequently today it remains unclear how to seamlessly integrate the LCA analysis in the global BIM based design workflow.

Many questions on how to unambiguously include discipline specific parameters in the Building Model are being treated in CEN TC 442 WG4 on 'Data Dictionaries' already. However, in order to tackle certain issues specifically associated to the execution of LCA studies based on BIM models, more insight in the possible workflows for this integration is needed.

Whereas most papers focus on the evaluation of the results of different BIM integrated LCA tools (including [1]) or the user requirements for individual LCA tools (including [2]), the objective of this study is to identify and develop feasible workflows to perform building life cycle analyses based on BIM models, together with the industry. Based on these workflows further guidelines can be developed for structuring the LCA data (generic, product/brand specific, sector average) for use in BIM workflows.



Insights were gained through an evaluation of existing tools in combination with focus group discussions with BIM and LCA experts from the construction sector (engineers, architects, contractors, manufacturers, government, research bodies).

2. Screening of existing tools and methods

For this study existing national and international tools and methods were screened, amongst which Elodie (France), Totem (Belgium), Tally, One Click LCA and USai. For the selection of tools, the main goal kept in mind was the establishment of a building LCA study and the link with a BIM software environment for (part of) the data collection or modelling. The evaluation focused on the integration of the LCA calculations with the BIM model, and more specifically on the type of data and calculation steps occurring within the BIM environment and those occurring within a separate LCA assessment tool. Specific attention was given to the required modelling approach in order to allow for the linking between the BIM and LCA environments (e.g. level of material or level of building element). The design and evaluation process is evaluated and broken down into different steps in order to better understand the interaction between them, as well as the implication in terms of possibilities and workflow.

2.1. Main elements and terminology of the BIM and LCA integration

Based on the evaluation of the tools a set of main elements and terminology can be described, relevant for the understanding of the integration of BIM and LCA and the definition of BIM-LCA workflows. Below an overview of the most relevant items is included.

Generic LCA database. Database containing generic LCA data that is not linked to a specific manufacturer or product.

Specific EPD database. Database containing LCA data that is specific for a certain manufacturer or product, usually based on a EPD (Environmental Product Declaration).

LCA profile. A set of LCA data for a certain material type or a combination of materials. This can either be a generic set of LCA data, an EPD, or a combination of both.

LCA software. Software tool specifically developed for the execution of an LCA. Expert tools include the possibility to calculate according to different LCA methodologies. Other tools usually include a specific database of LCA profiles (for a specific methodology). These tools support the insertion of material quantities (directly or via a file-import), the linking of LCA profiles to the materials or compositions, and the calculation, visualization and analysis of the environmental impact.

BIM objects. BIM objects are digital representations of building products which are used to build up a BIM model. BIM objects can be generic (e.g. a generic masonry wall) or can be provided by a manufacturer who can include all product and manufacturer specific parameters in the BIM object. A BIM object contains information on different parameters. LCA data can be associated to a BIM object through specific parameters.

Native BIM software. Software tool for modelling a building in 3D with the attribution of additional information to the elements within the model.

LCA plugin. An LCA plugin is a software component that runs within an existing computer software (e.g. a native BIM modelling software) and adds functionality to this software specifically designed to support a life cycle analysis.

IFC. IFC (Industry Foundation Classes) is an open file format facilitating the exchange of BIM models between software tools from different vendors.

BIM viewer. A software tool which allows for a BIM model to be inspected. A BIM viewer does not support the creation or modification of the (geometric) BIM model. However, certain BIM viewers support the addition or modification of certain parameters.

2.2. Landscape of tools and process steps for BIM based LCA

Since the introduction of BIM based design and life cycle analysis in the design practice, a wide variety of tools both for BIM and LCA have been developed, each supporting different steps in the BIM based and LCA based design process.

The process for designing a building in BIM and then using this information for performing an LCA study, contains at least these steps:

1. Modelling: The BIM model is developed by a BIM modeler. The geometry of the building is modelled based on BIM elements containing additional information.
2. Setting up a bill of quantities or BOQ: Based on the BIM model, a list of elements and/or materials with their respective quantities is established.
3. Establishing LCA profiles: the environmental impacts of the different materials and products used in the building are identified and quantified in LCA profiles. Depending on the situation, the LCA practitioner can fall back on generic or EPD-data. These LCA profiles can either be developed at the material level, or at the level of a building component (assembly of materials).
4. LCA profile attribution: The material quantities from the BOQ have to be linked to the corresponding LCA profiles (which are expressed in environmental impacts per unit). This might not always be an explicit step and could be integrated within the previous step where the LCA profiles are established.
5. Calculation of the environmental impact: based on the BOQ, the attributed LCA data and the LCA methodology specified in the tool, the LCA calculation can be executed.
6. Visualization and analysis: The results of the LCA calculation are visualized and analyzed by the LCA practitioner.

For this paper, we differentiate between four different types of tools: native BIM software, BIM viewers, LCA software and LCA plugins for native BIM software. The table below visualizes the supported steps in the design process for these different types of tools (**Table 1**).

Table 1. Supported steps in the design and life cycle analysis according to the type of tool.

	Modelling	Setting up BOQ	Establishing LCA profiles	LCA profile attribution	Calculation of env. impact	Visualization and analysis
Native BIM software	✓	✓				(✓)
BIM viewer		✓		(✓)		(✓)
LCA software			✓	✓	✓	✓
LCA plugin for native BIM software		✓		✓	✓	✓

3. Workflows for the integration of LCA and BIM

Different strategies can be used for organizing a design workflow that integrates building data coming from a BIM model in the LCA analysis. In relation to the direction of the data flow, two main strategies can be distinguished:

1. Geometrical and possibly also material related information is extracted from the BIM model in the form of a bill of quantities (BOQ). Based on this information on the quantities (and type of material) the LCA calculations are performed in specialized LCA software.
2. Specific LCA data can be added to the BIM model by use of specific parameters. The LCA calculation is performed within (a plugin for) the BIM software.

Some intermediate strategies can be determined between these two extremes. Below, five main strategies are described into further detail based on the screening of existing tools and expert discussions. In practice, more strategies can be conceived, combining aspects of the five proposed strategies. The

choice for a strategy depends on the tools used by the designer and LCA professional, and their respective available functionalities for integration, the availability of the relevant information in the BIM model, the availability of LCA data, the scope of the evaluation, etc.

3.1. Strategy 1: Bill of quantities (BOQ) export

A life cycle analysis always starts with an inventory of the building materials based on a bill of quantities (BOQ). For a BIM based project design, this BOQ can be extracted from the native BIM model in the form of a spreadsheet.

In this first strategy, the BOQ is (directly) imported in a dedicated LCA software. The remaining workflow takes place within the LCA software. The LCA practitioner manually links the different building components (with their quantities) to predefined LCA profiles available in the LCA software database or creates new LCA profiles where needed. The LCA calculation, visualisation and analysis is performed within the software as for a traditional LCA study. A representation of the workflow is available in **Figure 1**.

Iterative design might not be supported using this strategy. Depending on the tool used, importing an updated BOQ spreadsheet in an existing LCA calculation set, while preserving the already defined links between the building components and the LCA profiles, might not be possible. The data availability and verifiability depend on the quality of the data in the LCA software. A visualisation of the results (environmental impacts) in relation to the building elements depends on the visualization possibilities of the LCA software.

This workflow describes how most BIM integrated LCA calculations are currently performed.

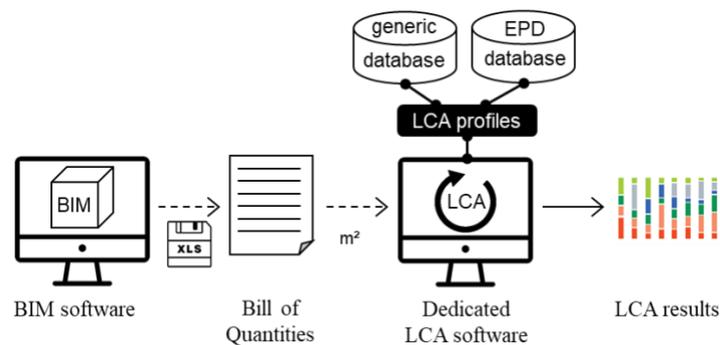


Figure 1. Workflow based on a bill of quantities (BOQ) export from the BIM model

3.2. Strategy 2: IFC import of surfaces

In the workflow defined by strategy 2, the geometric BIM model is imported “as such” in the dedicated LCA software. Usually, an open exchange format like IFC is used for the transmission of the BIM model, but the use of native BIM file formats is also possible, depending on the features the LCA software provides.

The imported data includes at least the geometric parameters, based on which the material quantities (surfaces, volumes) can be determined, but will in many cases include the Global Unique Identifier (GUID) and the component or material name as well. Based on these imported data, the LCA practitioner will link the building components to predefined LCA profiles available in the LCA software databases (which could be a generic or a product specific database, or a combination of both). Finally, the LCA calculation, result visualization and analysis is performed within the dedicated LCA software. See **Figure 2**.

The main difference with strategy 1 is the automatic import of the data and the possibility to maintain a link between the data. When the GUID is imported and stored in the LCA software, an iterative design process could be supported, allowing for quantities and descriptions to be updated based on a new version of the IFC file without losing the existing links to LCA profiles.

The Belgian TOTEM-tool is an example of this strategy [3].

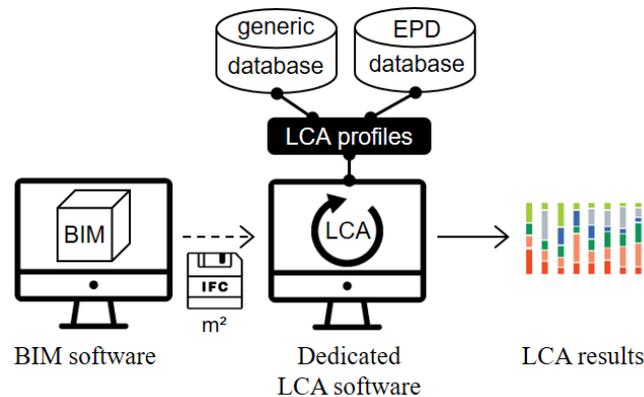


Figure 2. Workflow making use of an IFC import into the LCA software

3.3. Strategy 3: BIM viewer for linking LCA profiles

In the third strategy, the LCA profiles are attributed in an intermediate step in a BIM Viewer environment. This requires the export of a BIM model from the native BIM software by means of an IFC file. Within a specific BIM viewer, containing functionalities for this task and a list of available LCA profiles, the LCA practitioner or potentially the BIM modeler can attribute LCA profiles to the building components.

The geometric data is then sent to a dedicated LCA software, together with their associated LCA profiles. Based on these LCA profiles, the LCA calculation can be completed in the LCA software, followed by result visualization and analysis. The workflow is represented in **Figure 3**.

The advantage of this approach is that the attribution of the LCA profiles can occur within a 3D environment, while keeping the in-depth LCA analysis in a dedicated LCA environment. Also the link between the geometric data and the LCA profiles can be maintained for further reference during an iterative optimization process.

An example of this strategy is the eveBIM-viewer where FDES-profiles (=Environmental Product Declarations from the French program Inies) can be attributed to building components before exporting to the dedicated Elodie software [4].

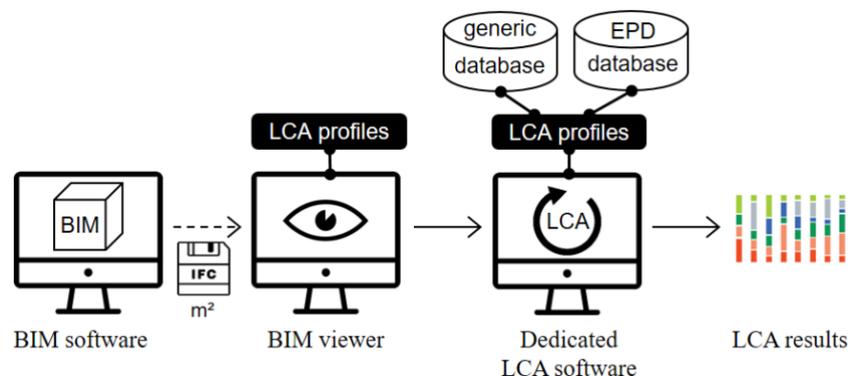


Figure 3. Making use of a BIM viewer to associate environmental data (LCA profile) to the building geometry.

3.4. Strategy 4: LCA plugin for BIM-software

Strategy 4 strives for a maximisation of design process steps to be performed within the native BIM environment, by means of specific LCA plugins. With these plugins, LCA profiles can be attributed to

BIM objects within the native BIM environment. All further steps, including the calculation, result visualisation and analysis are done within the LCA plugin (see **Figure 4**). Consequently, the dedicated LCA software is no longer used but replaced by the use of a plugin.

Up to now, this strategy seems to allow for LCA analyses with generic LCA data only (based on the databases of LCA profiles included within the plugin). An important advantage compared to the previous strategies is that the LCA results potentially can be visualized in the geometric model providing an instant view on the hot spots or most important impacts.

The tools Tally [5], One Click LCA [6], USai/Eco-Sai [7] and CAALA [8] work with plugins for BIM software.

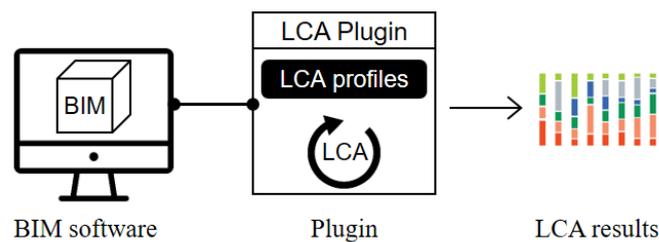


Figure 4. Workflow based on use of an LCA plugin for the BIM software.

3.5. Strategy 5: LCA enriched BIM objects

In the fifth strategy, LCA information is included in the BIM objects that are used in the BIM model, instead of being attributed to the appropriate building components in a later stage by an LCA practitioner. The LCA profiles are thus immediately associated to the geometric and material data inserted in the BIM environment. The further steps of this workflow could include a calculation and analysis with a plugin in the dedicated BIM software, or an export to a dedicated LCA software. A visualization of the workflow is given in **Figure 5**.

When generic BIM objects are used, generic LCA data will be used. However, manufacturer or product specific BIM objects could contain manufacturer or product specific LCA data as well. These BIM objects do not necessarily contain all the LCA data themselves, but could contain a reference to an LCA profile for which the data is stored in a dedicated LCA tool or database.

This strategy has a high potential as all data can be centralised within the BIM objects and a design optimisation process can potentially be supported with real-time information on the environmental impacts. On the other hand, with LCA profiles linked directly to the BIM objects, a trade-off between different materials might necessitate changing the BIM objects in the model, which is more laborious than changing the LCA profile in a dedicated LCA software.

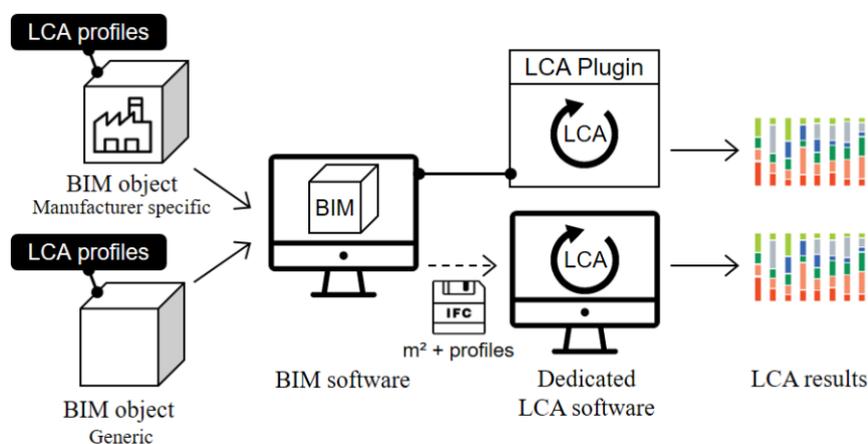


Figure 5. Workflow where BIM objects are enriched with LCA-based information or references.

For now, it appears this strategy has not been implemented yet, due to a lack of available BIM objects with LCA data, and a lack of consensus on how to structure LCA data and profiles. The level at which LCA data is available (e.g. EPD data for cement) will not always coincide with the level for which BIM objects are provided (e.g. wall). Furthermore, other difficulties have to be tackled first. LCA data is often valid for specific situations only (e.g. for a specific size of a certain building component). As a result, the LCA data might not be valid anymore after resizing of the BIM object.

4. Expert discussion on workflow and user needs

An expert group with Belgian LCA-practitioners was brought together in order to assess the current workflows for LCA analyses and to evaluate the future applicability of the different proposed workflows. Insights from these discussions have been integrated in the workflow assessment in the previous part. A more comprehensive report of the discussion on the applicability of the proposed workflow strategies for different disciplines and design and construction phases is given below.

4.1. Applicability of workflow strategies for disciplines and construction phases

Different needs exist in relation to the different disciplines making use of LCA and BIM, and the objective of the LCA study.

For example, for structural works, due to the low variety in used materials, it is feasible to perform an LCA in the early design phases based on a rough BIM model. Quantities are fairly easy to specify and the number of materials to be associated is limited. It would therefore be feasible to implement any of the proposed strategies for this type of analysis. Even in the absence of readily available BIM objects containing LCA data, a design office could invest in creating a set of BIM objects for the limited amount of materials used themselves, and thus implementing strategy 5 internally.

For the architectural design, the specifications have to be more detailed (loadbearing materials, insulation, finishing materials). Differences in materials will have significant impacts on the LCA results. When there is a trade-off between different building materials in an early design phase, it is very likely that an optimization from an environmental point of view is performed at the level of the building element, rather than at the building level, thus ignoring the relative weight of the building material in the total building. This optimization can easily be done within a dedicated LCA environment.

For a thorough building level LCA study for an architectural design to be executed in an early phase, Moreover, due to the large quantity of materials used in architectural design, an easier access to LCA data is needed. Several material choices and technical execution details are still open or specified with a very low level of detail. In that case, it is very likely that the BIM model does not contain sufficiently detailed information at the material level to allow for an LCA calculation. At that moment a need exists for a database with generic information on building compositions and their associated LCA profiles.

In this early phase, support for an iterative design process is essential too, rendering strategy 1 unfit for this situation.

Strategy 5 seems a promising workflow from an architect's perspective for providing easy access to LCA data, notwithstanding the current lack of LCA data enriched BIM objects and the difficulties this poses for manufacturers. However, it is less supportive for an iterative approach. When multiple material options without important geometric differences are to be evaluated, different BIM objects would have to be incorporated in the BIM model. In this situation, strategies 2, 3 or 4 might be more efficient, since multiple material options can be compared based on only one BIM model.

Special attention has to be given to public tenders, where the BIM model needs to be manufacturer independent. In these projects, the use of BIM objects with EPD data could therefore cause problems.

If the goal of the LCA is a "post-construction" assessment of the environmental performance (and thus not an optimization process) it becomes easier to determine which information should be available to allow for a calculation. In that case an approach where environmental data is linked to the objects in the BIM model (by means of parameters with a GUID) seems feasible. A complete BIM model of the building "as-built" can be fed with this specific information.

The most suitable workflow will thus be related strongly to the objective of the LCA calculation, the time phase in the project and the discipline.

4.2. EPD data in BIM models and objects

A specific point of attention concerns the use of EPD data associated to BIM objects. First of all an EPD can be country specific, including specific indicators or not, or being representative for the transportation or End of Life treatment in a specific country of region. The use of EPD information from different EPD programs within one BIM model should be avoided. A second point concerns the verifiability of the environmental data associated to BIM objects in a BIM model. For example, data from an EPD might be valid for a specific product with specific dimensions (e.g. a window of a certain size) but might lose its validity when the object is being scaled. Thirdly, it is very likely that EPD data will not be available for all materials or components of the building. In order to allow for a correct LCA evaluation within the BIM environment, there is a need for databases with generic objects including generic LCA data and for guidelines for the proper use of EPD data linked to BIM-objects.

5. Conclusions

The digitization of the design process through the use of BIM, and the growing need for the inclusion of environmental considerations early on in the design process, urges for an efficient exchange of building information between the design team and the LCA practitioner. Even though different tools supporting this integration already exist, there is still much uncertainty on how to best integrate the LCA analysis in the BIM supported design process.

This paper proposes five strategies for workflows, ranging from a BOQ export from a native BIM model to be imported in a dedicated LCA software, which corresponds to how most LCA practitioners perform the integration today, to the inclusion of LCA data in BIM objects before they are incorporated in the BIM model.

Besides the availability of tools and databases to support the proposed workflows, many other considerations influence the choice for a strategy to be implemented in a design practice, including the need for support for an iterative design approach, the use of generic versus product specific LCA data, the need for real-time feedback for design decisions, etc. Nevertheless, the five proposed strategies form a basis for further research on the optimization of the integration of LCA studies in BIM supported design processes.

Acknowledgements

This research was supported by the Belgian Federal Public Service Economy, through the prenormative research project “CoDeC II – Communication framework for Digital Construction II”, and the European Fund for Regional Development (FEDER-EFRO) through the project “Living Labs Brussels Retrofit”.

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