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## Analyzing BIM interoperability for LCA purposes

M. Dupuis<sup>a\*</sup>, A. April<sup>a</sup> and D. Forgues<sup>a</sup>

<sup>a</sup>*École de technologie supérieure, 1100 Notre-Dame West, Montreal, Quebec, Canada*

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### Abstract

The use of building information modelling (BIM) is increasingly popular and results in the BIM model becoming the central data source in a construction project. The information available in BIM is hard to use because it lacks interoperability. This paper assesses every strategy to share data from BIM in order to support a life cycle assessment (LCA) for a whole building at every step of the BIM model design. Every open file format concerning the BIM is analyzed to determine if one file format can fulfill the data requirements of an LCA. Among all of these file formats, IFC is the best-known and most detailed format. An in-depth analysis of the IFC data schema and syntax is performed to determine whether the construction industry requires a specific file format for LCA purposes or whether one of the existing open file formats can be used as a data source.

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### 1. Introduction

In recent years, a wave of new technology has emerged in the construction industry, including building information modelling (BIM) technologies. With these, a lot of new information is readily available for analysis and enables the optimization of building design. This new information can also be used to coordinate the construction process, to optimize cost and for many more aspects. One of these aspects is sustainability. Today, given that the construction industry contributes more than 39% of greenhouse gas emissions in the US [8,10], stakeholders of a building project are concerned with their environmental footprint [2,7,10]. One of the common processes used to assess the environmental impact of a product is to perform a lifecycle assessment (LCA). The process is well known but underused [7] in the construction industry. This paper will assess how to use new information from BIM in the design process of a building to perform an LCA for a whole building at each step of the building project.

### 2. Literature review

#### 2.1. LCA of a whole building

Determining the LCA of an entire building is a complex process that needs a lot of data [3,5,7,10,11]. To simplify the LCA process, many research projects use the BIM model as their data source [3,5,8,10] but it is not as simple as it

\*Corresponding author: Mathieu Dupuis Email: [mathieu.dupuis.1@ens.etsmtl.ca](mailto:mathieu.dupuis.1@ens.etsmtl.ca)

seems and the lack of interoperability of BIM software is well documented [2,4,8]. Sabol [9] proposes three strategies to improve the interoperability of the BIM data: 1) designing software that uses an application program interface (API); 2) using an open database connectivity (ODBC) technology; or 3) using a specialized file format.

Using an API allows us to create new features on top of BIM software. The new feature can be as simple as the ability to export BIM data in a new file format or as complex as a complete LCA software. Using an API is the most flexible strategy of the three proposed but requires a high level of knowledge in software engineering and will require adjustments whenever the BIM software version changes.

The second recommended strategy is to use ODBC technology. This technology can extract the data from a BIM model and store it in a database like Microsoft SQL Server. Once the data is transferred into a database, it is easy to query and extract the desired data by using the Structured Query Language (SQL). The downside of ODBC technology is that the resulting data schema is not standardized and would be different for each BIM software currently on the market.

The third strategy is to use a specialized file format. For this strategy, only non-proprietary formats would be considered because proprietary formats, like the Revit file format, are regulated by license agreements that prohibit their use in other software without prior agreement. Today, many open file formats exist for the construction industry such as: BIMXML, CityGML, COBie, gbXML and IFC. After an in-depth analysis of each of these formats, it was concluded that none contained the required data for an LCA, with the exception of the IFC file format (see Table 1).

*Table 1. Focus of open formats available*

| Format  | Focus  | Building perspective described as         |
|---------|--|---|
| BIMXML  | Simplified spatial building model            | Spaces and rooms                          |
| CityGML | Model a city                                 | Massing forms                             |
| COBie   | Information handover for facility management | Component, object's type, assembly, space |
| gbXML   | Operational energy analysis                  | Space and room with thermal property      |
| IFC     | Building modelling                           | Object with a high level of detail        |

The list of data elements required for an LCA at each step of the BIM model design is described by Dupuis [3] (see Table 2), and only the IFC file format possesses enough detail to describe each layer of material of an assembly and provide quantities (area and volume) by object.

*Table 2. Data needed for each level of development (LOD) of a BIM model for LCA purposes*

| LOD | Definition  | Data needed for LCA  |
|-----|---|--|
| 100 | The element is represented with a generic representation  | Metadata about the building<br>Massing form quantities   |
| 200 | The element is represented with a generic object  | Objects / Object's type Unifomat II code<br>Objects / Object's type quantities                           |
| 300 | The element is represented as a specific object without a specific assembly or with partial assembly      | Objects / Object's type quantities<br>Material quantities<br>Material function (to detect missing layer) |
| 350 | The element is represented as a specific object with a specific assembly                                  | Material quantities<br>Objects / Object's type quantities  |
| 400 | The element is represented as a specific object with a specific assembly and with the installation detail | Material quantities<br>Objects / Object's type quantities  |
| 500 | The element is a field verified representation  | Material quantities<br>Objects / Object's type quantities  |

### 3. Analyzing IFC for LCA purposes

The IFC file format is the best-known open file format in the construction industry and has the greatest potential for standardizing a BIM data exchange [9]. Today, almost every BIM tool supports the export or the import of IFC files and the format is somewhat standardized. The syntax of IFC, called STEP, is described by the international standard ISO 10303 and its data schema defines more than a thousand entities, all described by the international standard ISO 16739-1 [6]. Based on these two standards and some IFC files exported from different BIM tools, we assessed whether the IFC file format is suitable as a data source for LCA purposes. As described in Table 2, to be a suitable data source, the IFC file must contain the following information:

- Quantities related to:
  - Massing form;
  - Object;
  - Object's type;
  - Material.
- Informations required to impute or qualify quantities:
  - Material's function;
  - Unifomat II code for both Object and Object type;
  - Metadata about the building.

The following sections describe these data items in more detail.

#### 3.1. Quantities

The quantity of an object's type can be calculated by aggregating the quantity of every object associated with this object's type. The quantity of a massing form, given that it is an object type, is calculated in the same way as any other object's type. Lastly, the quantity for each material is the product of the object type quantity multiplied by the ratio of this material for that object type. The determination of the ratio is explained later in this section.

To extract the quantity of an object from the IFC file format, two methods are possible. The first method is to calculate the area and the volume of each object directly from 3D geometry. The IFC file format describes 3D geometry using a combination of one or multiple entities based on 24 types of representations [1]. Due to the scope of our research project, extracting the area and volume in 24 different ways was too long and too complex.

The second method is to extract the quantity based on the parameters of the object. With this method, the first challenge is that the user needs to set all the proper options in the IFC file export window so as to export the IFC file with the required data for the LCA of a whole building. In our tests, we found that the contents of two IFC files differed for different BIM software, even if all the IFC file export options are properly set. As an example, we compared two IFC files generated by two different versions of Autodesk Revit, where the object's quantity is linked to an object by a different property set with different parameter names (see Table 3). This variation could be managed by mapping property names and property set type to each BIM tool and BIM tool version.

Table 3. Differences between two IFC exports

| Element              | File 1 (See Appendix A)   | File 2 (See Appendix B)          |
|----------------------|---------------------------|----------------------------------|
| Software             | Autodesk Revit 2017 (ENU) | Autodesk Revit Architecture 2011 |
| Property set type    | IFCELEMENTQUANTITY        | IFCPROPERTYSET                   |
| Property set name    | BaseQuantities            | PSet_Revit_Dimensions            |
| Area property name   | GrossSideArea             | Area                             |
| Volume property name | GrossVolume               | Volume                           |

The next piece of information to extract from the IFC file is the ratio of each material in the object and its function. In our observations, most of the time the assembly is described in the object's type. The object is linked to the object's type by the entity "IFCRELDEFINESBYTYPE" and the list of material is linked by the entity "IFCRELASSOCIATESMATERIAL". The ratio of each material in the object is expressed with a thickness by square meter in the entity "IFCMATERIALLAYER". The volume of material can be calculated by multiplying the area of the object by the thickness of the material layer.

### 3.2. Information required to impute or qualify quantities

The detection of a missing layer of an object's type is based on the material function (e.g. an exterior wall missing a layer of material with the function "Thermal/Air layer"). However, the material's function is not found in any analysed file. After further analysis of the IFC data schema, the IFC format cannot contain the description of the function of a material or any additional information.

The last element needed concerning the object or the object's type is the Unifomat II code. The Unifomat II code helps to identify more precisely an object or an object's type when its description is irrelevant (e.g. "Product A" to describe an exterior wall). Unifomat II code is associated with the object or the object's type with the entity "IFCRELASSOCIATESCLASSIFICATION".

The metadata helps to impute quantity more precisely or to share information that affect the whole building. A metadata is a parameter that is structured with a name and a value (e.g. Name: "Building a lifetime", Value: "75"). After several tests to register global parameters in Autodesk Revit and export IFC files, we found that the metadata parameter was not transferred to the IFC file in any way. After validating the data schema of IFC, we found that IFC contains a global entity named "IFCBUILDING" representing the building. To add information that applies to the whole building, such as metadata, an entity "IFCPROPERTYSET" needs to link to the entity "IFCBUILDING".

## 4. Conclusion

The construction industry has various files that can share specialized information but at the time of writing this paper, no file format is specialized to share information between BIM and an LCA. After comprehensive analysis, it was determined that the IFC was the best file format to be used as a data source for the LCA of a whole building. Almost all of the information needed for an LCA can be contained in the IFC file. Our analysis has shown that the contents of an IFC file varies greatly based on the BIM software used and the export options selected by the user. All of these variations need to be considered to use the IFC file format and with more than a thousand entities to examine and understand, it is a complex and tedious task. For global parameters, we have seen that IFC can handle this kind of information but Autodesk Revit does not use IFC to its full potential. The only drawback with the IFC data schema is its inability to add information for a material, such as the material's function. This information is crucial for detecting

missing layers in an assembly. The IFC format will continue to evolve, becoming more flexible and maybe one day, BIM software will use more of the IFC features to support more information with regards to material. Meanwhile, the industry will need to create a new specialized format to share data between BIM and the LCA. This new specialized file format will need to be generated with an API of a BIM software until it becomes fully supported by the BIM software itself or until a new version of the IFC format can fulfill all the data requirements of the LCA.

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## Appendix A. IFC file 1

File generated from the Revit 2017 example file “Sample System Project”

```
#1=IFCORGANIZATION('$,'Autodesk Revit 2017 (ENU)',$,,$);
#5=IFCAPPLICATION(#1,'2017','Autodesk Revit 2017 (ENU)','Revit');
...
#537293=IFCWALLSTANDARDCASE('3XrBtx9eX7mQE6EqWHPk2W',#41,
    'Basic Wall:STB 30.0 Rot:573298',$','Basic Wall:STB 30.0 Rot:563456',#537266,#537291,'573298');
#537304=IFCRELDEFINESBYPROPERTIES('1RmJMst4LCfPj0I4gbOuNN',#41,$,,$,(#537293),#537302);
#537302=IFCELEMENTQUANTITY('2RnzV9aiTCPvHT7sUlrItz',#41,'BaseQuantities',$,,$,
    (#537296,#537297,#537298,#537299,#537300,#537301));
#537296=IFCQUANTITYLENGTH('Height',$,,$,3405.82826312155);
#537297=IFCQUANTITYLENGTH('Length',$,,$,8235.00000008147);
#537298=IFCQUANTITYLENGTH('Width',$,,$,300.);
#537299=IFCQUANTITYAREA('GrossFootprintArea',$,,$,2.47050000002445);
#537300=IFCQUANTITYAREA('GrossSideArea',$,,$,28.0469957470834);
#537301=IFCQUANTITYVOLUME('GrossVolume',$,,$,8.41409872412505);
...
#537324=IFCWALLTYPE('3XrBtx9eX7mQE6EqWHPiRI',#41,
    'Basic Wall:STB 30.0 Rot',$,,$,,$,'563456',$,$.STANDARD.);
#1046230=IFCRELDEFINESBYTYPE('2P_uP6Oz13fO3cLNLBR5qm',#41,$,,$,(#537293,#537513),#537324);
#537331=IFCRELDEFINESBYPROPERTIES('3gAvc6bvjA3Ae2Rv7kN7H3',#41,$,,$,(#537293),#537329);
#537329=IFCPROPERTYSET('3XrBtx9eX7mQE6CBKHPk2W',#41,'Pset_WallCommon',$,
    (#537325,#537326,#537327,#537328));
...
#1041241=IFCRELASSOCIATESMATERIAL('0g2kHgMgLazPXey59ofISJ',#41,$,,$,(#537324),#537320);
#537320=IFCMATERIALLAYERSET((#537318),'Basic Wall:STB 30.0 Rot');
#537318=IFCMATERIALLAYER(#537308,300.,$);
#537308=IFCMATERIAL('Stahlbeton - Ortbeton - Rot');
```

## Appendix B. IFC file 2

File from NIBS website: <https://portal.nibs.org/files/wl/?id=4DsTgHFQAcOXzFetxbrRCECPbbfUqpgg>

```
#1=IFCORGANIZATION('$,'Autodesk Revit Architecture 2011',$,,$);
#2=IFCAPPLICATION(#1,'2011','Autodesk Revit Architecture 2011','Revit');
...
#3797=IFCWALLSTANDARDCASE('2O2Fr$t4X7Zf8NOew3FNtn',#33,
    'Basic Wall:Exterior - Brick on Block:138062',$,
    'Basic Wall:Exterior - Brick onBlock:130892',#3781,#3796,'138062');
```

```
#3871=IFCRELDEFINESBYPROPERTIES('35P9FVrsf6NgTkU$WnQOmz',#33,$,$,(#3797),#3870);  
#3870=IFCPROPERTYSET('30Iq7jVDv0KRtnFHa6i3mq',#33,'PSet_Revit_Dimensions',$(#3822,#3823,#3824));  
#3822=IFCPROPERTYSINGLEVALUE('Length',$,IFCLENGTHMEASURE(8.383000000000001),$);  
#3823=IFCPROPERTYSINGLEVALUE('Area',$,IFCAREAMEASURE(13.61184000000174),$);  
#3824=IFCPROPERTYSINGLEVALUE('Volume',$,IFCVOLUMEMEASURE(5.676137280000731),$);
```

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