A Proposition to Extend CityGML and ADE Energy Standards for Exchanging Information for LCA Simulation at Urban Scale

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Abstract Environmental performances assessment of urban projects is essential to meet the current challenges of urban sustainable development. In recent years, Life Cycle Assessment (LCA) has been applied to urban scale to assess complex systems such as districts, urban facilities and territories. Yet, application of LCA to large scale is challenging in terms of data modelling. To overcome this challenge, integration of Building Information Model (BIM) to LCA could reduce efforts during the data acquisition, as well as allowing the feedback of LCA results into BIM. To ensure interoperability e.g. with energy simulation tools, digital mock-up using an open information standard must be preferred. To answer this need, the Open Geospatial Consortium (OGC) developed the open standard CityGML which is an XML-based data model that defines classes and relations for 3D object in cities (e.g. buildings, roads, water bodies etc.). This format also provides for domain-specific extension to other objects or attributes using Application Domain Extensions (ADE). To date, LCA data requirements have not been fully integrated into the CityGML format nor its ADE. The aim of this paper is to propose extension of CityGML and Energy-ADE standards for exchanging information for LCA simulation at urban scale. The scope of the study is limited to the integration of information necessary for LCA of buildings' construction and renovation. First, data requirements are listed and then compared to CityGML and Energy-ADE

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structures to identify missing information. Finally, propositions and recommendations are presented to fully integrate information needed for LCA at urban scale into CityGML and Energy-ADE. This paper paves the way for further integration of LCA models with CityGML.

1 Introduction

In the construction sector, LCA has been used since the 1990s to evaluate construction products and buildings [1]. For few years, LCA has extended to urban scale, and is more and more used to assess urban precincts and building stocks at large scales [2]. Performing LCA at building and urban scale requires to collect large amount of information -data- on the foreground system to complete the life cycle inventory (LCI). This routine of data collection is time and effort consuming if repeated for different simulations (e.g. energy, cost, environment simulations) [3]. On the other hand, the integration of Building Information Model or Modelling (BIM) to building and urban LCA can reduce efforts during data acquisition, as well as allowing feedback of LCA results into BIM for results visualization.

Building Information Modelling (BIM) is a working process where digital representations of physical and functional characteristics of building and civil engineering objects are processed and managed. Building information models (BIMs) are data stocked in files which can be exchanged or networked to support expert analysis and decisions about a building or other built asset. They contain information regarding objects, geo-localization, geometry and semantic data [4].

In order to ensure interoperability with different software (e.g. with energy simulation tools), digital mock-up using an open information standard must be preferred.

1.1 *Open BIM Standards at Building Scale*

BIM is often associated with open data structures for representing information such as the Industry Foundation Classes (IFC) and Green Building XML (gbXML) formats at building scale and LandXML and CityGML formats at urban scale. Such data structures are intended to describe building and civil engineering construction industry data in a neutral and open manner i.e. they are open file formats that are not controlled by a company or a group [4].

At building scale, IFC format has a wide scope and is compliant with data requirements of building LCA [5] while gbXML format is specific to export data used by energy tools [6]. Some building specific LCA tools are already compatible with the IFC and gbXML formats. These international open formats ensure that any Architecture/Engineering/Construction (AEC) software understand and operate properly technical and geometrical information from BIM [3]. They greatly enhance interoperability between AEC software.

1.2 The CityGML Format and Its Application Domain Extensions (ADE)

At urban scale, the international open standard CityGML is an XML-based data model that defines classes and relations for 3D object in cities (e.g. buildings, roads, water bodies etc.). This format also provides for domain-specific extension to other objects or attributes using Application Domain Extensions (ADE) [4].

The Energy-ADE extends the CityGML Standard by features and properties necessary to perform urban energy simulation and to store the corresponding results [7, 8]. It contains information concerning construction, materials, building occupancy, energy and systems. Moreover, developers of this ADE highlight that “the Energy ADE is structured modularly in order to potentially reuse and extend some of its modules in other domains and applications” [8]. In other words, the data model developed in this ADE can be potentially extended to integrate data required for urban scale LCA.

To date, no LCA tools or studies were identified that developed a link with CityGML files to perform urban scale LCI. An important issue related to the integration of BIM and LCA at urban scale is that LCA data requirements have not been fully integrated into the CityGML format nor its ADE.

1.3 Aims and Approach

The aim of this paper is to propose ways for extension of CityGML and Energy-ADE standards in order to exchange information for LCA simulation at urban scale. The scope of the study is limited to the integration of information necessary for LCA of buildings’ construction and renovation. First, data requirements are listed and then compared to CityGML and Energy-ADE structures to identify missing information. Finally, propositions and recommendations are presented to fully integrate information needed for LCA at urban scale into CityGML and Energy-ADE.

2 Identification of Data Needs for LCA at Urban Scale

2.1 LCA Methodology at Urban Scale

To perform LCA at urban scale, the physical boundaries of the urban project under study have to be defined. All objects and flows located within these physical boundaries are identified. This includes in particular the following objects:

Table 1 Example of aggregated results of LCA at urban scale

Indicators	Value
Total primary energy consumption (kWh/year)	147,706,783
Total non-renewable primary energy consumption (kWh/year)	141,642,624
Global warming (kg CO ₂ eq/year)	4,463,791
Water consumption (L/year)	317,981,008
Hazardous waste disposed (kg/year)	2553
Non-hazardous waste disposed (kg/year)	2,024,629
Radioactive waste disposed (kg/year)	7222
Atmospheric acidification (kg SO ₂ eq/year)	22,399
Photochemical ozone creation (kg C ₂ H ₄ eq/year)	839

- Buildings;
- Energy and water flows related to building consumption, during use;
- Transport infrastructure (roads, cycle tracks, pedestrian paths, parking, rails);
- Network infrastructure (electricity, heat, water, lighting);
- Other (activity resources, green areas).

The scope of the LCA is set to include input and output flows of materials (including water) and energy related to each life phases of the project (production and provision of construction materials, construction phase, use phase and end of life), in accordance with a functional unit and an evaluation period [9].

The environmental impacts are then calculated from these flows, thanks to environmental databases that can be specific to the construction sector; such as the German ökobau database [10] or the INIES database (French national reference database of environmental declarations for products, equipment, and services in the construction sector) [11].

Depending on the objectives of the LCA and the nature of the urban project (e.g. renovation operation, new construction), the environmental impacts of each object are 100% allocated to the project or allocation rules can be identified. The LCA result is a set of environmental indicators that reflect the environmental burden of the urban project. These results can be aggregated or presented for each life cycle phase of the project, or for each object. In Table 1, results obtained for a LCA study in the Parisian region are presented.

2.2 Data Needs for LCA at Urban Scale

To provide these results, a considerable amount of data related to each object under study has to be collected (general information, materials and products used, quantitative data ...). Some information contained in the CityGML standard can be used to reduce data acquisition efforts. However, data requirements for LCA have not yet been fully integrated into the CityGML standard. An important issue related

to the integration of LCA data into the CityGML is related to the diversity of data needed, and to its quality, which can affect the precision of the results.

Data needs have been identified based on our experience from the development of the building LCA tool Elodie [12] and based on data requirements of the future French building regulation 2020 initiated by the “Energy- Carbon” labelling process [13]. Depending on the objective of the LCA study, and the data availability, a screening, simplified or complete/detailed LCA approach can be applied [14]. In this paper, we focus on data structuring for the environmental evaluation of building objects and energy consumption during use. Data structuring for environmental evaluation of other objects such as transport or utility infrastructures are not addressed in this work. Data needs considered in this work for environmental evaluation at urban scale of building objects can be structured into three categories, which are described below.

2.2.1 Building Object: General Data

General information, related to each building object inside the area under study is included into this module of data. The geometry of the building, height, number of floors and floor area are used for the quantification of construction materials when detailed data is not available. The building typology (e.g. individual house, collective dwelling, office building ...) is also needed when no detailed data about construction materials is available. This will mainly help the application of environmental indicators ratios for the evaluation depending on the typology. Other general data, such as construction year, number of occupants, housing units, type of operation (new construction or renovation) has to be collected. Table 2

Table 2 Data needs for building object, general data

Data needs	Type (unit if specified)
Building typology	CodeList
Floor area	Decimal (m ²)
Geometry	Geometry
Construction year	Date
Number of storeys	Integer
Height	Decimal
Type of operation	CodeList
Number of occupants	Integer
Housing units	Integer
Glazing ratio	Decimal
Renovation actions	String
Main structure type	CodeList
Main structural material	CodeList
Main filling material in facade	CodeList
Foundation type	CodeList

recapitulates all building’s general data needed and their related types and unit. Data type *CodeList* is used when the data can be selected from a list.

2.2.2 Building Object: Envelope, Products and Systems

This module of data contains information related to the walls, roofs and floors as well as information related to products and energy systems installed in each building. Data in bold in Table 3 is the minimum data set to collect to perform a simplified LCA. It describes surface components type such as roofs, floors, walls etc. for the building. To perform a simplified LCA, each surface component in the building has to be further described by information on its constructive system (e.g. for a wall type component, it can be a frame wall, a masonry wall ...) and by its main material (concrete, wood ...).

To perform a detailed LCA, the quantity and service life of any construction product and system has to be collected. Other information, such as construction package corresponding to the product or system and a field to describe its technical characteristics is needed. This information is necessary to link an environmental ID to the product or system.

2.2.3 Building Object: Energy Consumption During Use

This module of data contains the information concerning the energy consumption of the building object during its use phase. It can be connected with the information contained within the Energy ADE. For LCA at urban scale, final energy consumption of each end use type (heating, cooling, hot water for domestic use, lighting ...) must be quantified. This information is then linked to specific data with an environmental ID number, to evaluate the environmental impacts of energy

Table 3 Data needs for building object: envelope, systems and products

Data needs	Type and unit
Construction package	CodeList
Description field	String
Quantity	Decimal
Service life	Integer
Component type (wall, roof, floor ...)	CodeList
Construction system (e.g. flat roof if the component type is roof, ...)	CodeList
Main material (concrete, wood ...)	CodeList
U value (for thermal boundaries)	Decimal
Nominal power (for energy systems)	Decimal
Environmental identifier	Database Name + Id

Table 4 Data needs for building object: energy consumption during use

Data needs	Type
Type of energy (electricity, gas, biomass ...)	CodeList
End use (heating, air conditioning ...)	CodeList
Final energy consumption, for each energy type and end use type	Decimal (kWh)
Environmental ID	Database Name + Id
Primary energy factor	Decimal

consumption, for each end use type and for each type of energy (electricity, natural gas, fuel, pellets, wood, coal ...) (Table 4).

3 The CityGML and Energy-ADE

The building physics module (represented in Fig. 1) of the Energy-ADE extends the *building* class with new attributes and defines entirely new concepts suited for the energy simulation tools. A building is thus composed of *thermal zones* which serves as space units for the building heating and cooling calculation. Those *thermal zones* are bounded by *thermal boundaries* that can be optionally linked to geometrical *boundary surfaces* (e.g. Roof Surface, Wall Surface ...) of the CityGML 3D building description. *Thermal boundaries* are described by a construction object which specifies global thermal properties at the wall scale and optionally describes a sequence of layered material, themselves described by their physical properties.

At first, one could try to extend the material description with an environmental product declaration (EPD) database identifier. This is not satisfactory for two reasons. First, this would only allow to specify the environmental properties of thermal boundaries, and making it dependent to the arbitrary thermal zoning of the building. Second, this would not allow to account for other components such as stairs, HVAC systems and network. Thus, new propositions are needed in order to integrate environmental data into CityGML.

4 Proposal

In order to overcome the Energy-ADE limitations, new attributes are added to the building class. Those attributes are:

- The *Energy consumption* attribute, which describes the data needed to perform LCA related to energy consumption. This attribute gives the final energy consumption *value* (kWh) for each *end use* (domestic hot water, electrical

Fig. 1 Current structure of energy-ADE building physics module

- appliances, lighting, space cooling, space heating, ventilation or auxiliary) and *energy source* (coal, chilled water, electricity, fuel oil, hot water, natural gas, propane, steam, wood chips, wood pellet). An *environmental ID* is associated to the data for the calculation of environmental indicators.
- Generic attributes such as *Main structure material* (Concrete, Cellular concrete, Wood, Reconstituted wood, terracotta ...) are added to the building class to perform screening LCA when specific data is not available (cf. Fig. 2).
 - We propose then to create a new concept class *Component*. This new class can be added to any city object to specify an Environmental Product Declaration identifier (*environmental ID*) and a quantity. A *service life* attribute provides information to calculate the component replacement rate during the city object life time. This class is then declined into four children classes: *Surface Component*, *Network Component*, *System Component*, and *Other Component*.
 - The *Surface Component* class describe components such as walls, floors, roofs ... when a detailed characterization of products and materials composing the building is not available. The *construction system* and main *material attributes*

Fig. 2 Proposal for the integration of LCA data requirements into CityGML and energy-ADE standards. New concepts proposed appear in green

give a generic description of the surface component, which supports simplified LCA. Information contained in the *construction* attribute can be used to specify more precisely the surface component.

- The three other children classes (*Network Component*, *System Component*, and *Other Component*) describe individual products, systems and networks in the building when detailed information is available. A *gml name* is defined to characterize the component (e.g. Concrete stairway, Individual boiler etc.). Through this description, the link to an *environmental ID* related to the product, system or network can be done. Specific information for the systems such as *nominal power* for system components and *network type* for network components has to be recorded. A *Construction Package* is allocated to any component. This allows the aggregation of LCA results for each construction packages such as:
 - Roads and networks,
 - Foundations and infrastructures,
 - Superstructure/Masonry,
 - Roofing/Frame/Waterproofing,
 - Partitioning/Doubling/Interior carpentry,
 - Facades/Exterior Carpentry,
 - Coverings (floor, wall, ceilings)/Decoration products,
 - HVAC,
 - Plumbing-sanitary,
 - Energy networks (high voltage) and communication networks (low voltage)
 - Equipment for local electricity production.

Figure 2 recapitulates the proposed structure for environmental data.

5 Conclusion and Perspectives

In this paper, propositions and recommendations are presented to integrate information needed for building LCA at urban scale into CityGML and Energy-ADE. The structure proposed is meant to be suitable for screening, simplified or detailed LCA of the building. Validation of this new developments will be achieved through an iterative process. During the next months, a test phase will allow confronting the proposed data structure with real projects and software integration issues. In addition, the structure and the completeness of the schema should be discussed within the LCA practitioners' and Energy-ADE developers' communities.

Moreover, this work is limited to the description of building components, systems and energy consumption. To perform full life cycle assessment of building as defined by the European standard EN 15 978 [15], further work is required to integrate information on water consumption, waste production, mobility needs and worksite. Finally, to perform urban scale LCA, information required on utility networks, transport infrastructures and public spaces should be listed and integrated into the CityGML standard.

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