D6.5

Advance Mapping Structures and Standards

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Colophon

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Publishable executive summary

It is the central goal of the STREAMER project to develop advanced design methodologies and tools for new or largely retrofitted buildings in hospital districts. In this context, an important approach is to base the design process on an integrated, semantically structured data model of the planned building and the existing neighbourhood (“Design-model”). In the various phases of the design process, different software tools supporting modelling, assessment, simulation or visualization need to access the design model. STREAMER task 6.3 aims at identifying potential interoperability issues of the involved software tools and at developing strategies for solving these issues. This report documents the main results of this research.

In STREAMER, the main reason for interoperability problems is the use of software applications from different technological areas. Among these are tools from the area of Building Information Modeling (BIM), Geospatial Information Systems (GIS), and tools for energy demand simulation. Consequently, this report first of all reviews the relevant standards for data models and web-based data exchange in the different areas. It is found that different standards are being used in the BIM and GIS areas. Big differences exist on the conceptual level already. In the BIM area, conceptual data models frequently are represented in EXPRESS, while many GIS standards use the Unified Modeling Language (UML). The Semantic Web domain mainly uses ontologies for data modelling purposes, but this technology is less supported by commercially available design tools.

The most important data model in the BIM area is “Industry Foundation Classes” (IFC) developed by buildingSMART (bSI).It supports all phases of a building’s life cycle and all building-relevant processes. For specific tasks in the design process, additional BIM standards may be relevant: BIM Collaboration Format (BCF) for supporting communication between different BIM tools, Green Building XML (gbXML) as an exchange format for energy simulation systems, VDI3805 / ISO /DIS 16757-1 for the exchange of product data in the area of heating, ventilation and air conditioning (HVAC), and the International Reference Life Cycle Data system (ILDC) format for the integration of life cycle information.

In the GIS area, a large number of different standards for buildings and energy-relevant data exist. The most prominent one is the City Geographic Markup Language (CityGML), an international standard for virtual 3D city models. In addition, potentially STREAMER-relevant standards have been developed for the European geospatial data infrastructure INSPIRE. Furthermore, a large number of building models are represented in Keyhole Markup Language (KML). Unfortunately, most of these standards hardly support energy-relevant attributive information. In this context, it is important to note that CityGML implements an intrinsic extension mechanism. Furthermore, a large amount of public available GIS information does not fit to any of these standards. As a consequence, it will be necessary in STREAMER to also access data in proprietary formats like ESRI Shapefile, and to use the very large database of the OpenStreetMap (OSM) initiative.

For web-based access to model data, BIM- and GIS also use different standards. The report gives a short overview of the most import web service standards for GIS information developed by the Open Geospatial Consortium (OGC). The “BIM Server Information Exchange” (BIMsie) standard from buildingSMART is mentioned.

It is unlikely that all STREAMER-relevant data will be available in a uniform data format, which is supported by all system components. The main part of this report therefore discusses a number of technologies for mapping one data model onto another one. This will be illustrated by STREAMER

relevant examples. In a “transformation”, when taking into account geometry as well as semantics of the objects involved, the target model has less than or an equal amount of information as the initial model. If it is necessary to add specific information prior to the transformation, the process is called “data enriching”. Mapping strategies are not needed in case an application supports more than one exchange format and is able to generate a consistent internal data model based on different data sources. The IFCExplorer application makes first steps in this direction, which are described in this report.

Data linking is an alternative approach to consolidate different data sources. On a lower level (e.g. references to externally stored documents, databases or code list registries), this technology is supported by most of the BIM and GIS data models mentioned. Semantic web technology also allows for data linking on a semantic level, provided that ontologies suited for the data models involved and their mutual correspondences are available. It is not yet clear whether corresponding data will be available in the STREAMER project, and for which processes they are used, if necessary.

Finally, the report lists a number of recommendations for the usage of standards and mapping techniques. The principal strategy should be to generate a consistent IFC model, which is maintained over all stages of the design process. For selected modelling and evaluation processes, which are supported by tools without adequate IFC support, the usage of other data formats will be unavoidable. In these cases, suited linking, transformation or data enriching strategies need to be developed. This is also necessary when the IFC based design model has to be consolidated with GIS data of the neighbourhood in an application that does not support different data models.

List of acronyms and abbreviations

- ACA: AutoCAD Architecture
- ADE: Application Domain Extension
- AEC: Architecture, Engineering and Construction
- ALKIS: Amtliches Liegenschaftskatasterinformationssystem
- API: Application Programming Interface
- BCF: BIM Collaboration Format
- BIM: Building Information Modelling
- BIMsie: BIM Service Interface Exchange
- BRep: Boundary Representation
- bSI: buildingSMART International
- CAAD: Computer Aided Architectural Design
- CB-NL: NEDERLANDSE CONCEPTENBIBLIOTHEEK
- CEA: Commissariat à l'énergie atomique et aux énergies alternatives
- CityGML: City Geography Markup Language
- COBie: Construction Operations Building Information Exchange
- CRS: coordinate reference system
- CSG: Constructive Solid Geometry
- CSTB: Centre Scientifique et Technique du Bâtiment
- DXF: Drawing Interchange Format
- ELCD: European Reference Life Cycle Database
- GIS: Geographic Information System
- GML: Geography Markup Language
- GUID: Global Unique Identifier
- HTML: Hypertext Markup Language
- HVAC: Heating, Ventilation and Air Conditioning
- IFC: Industry Foundation Classes
- IGES: Initial Graphics Exchange Specification
- ILCD: International Reference Life Cycle Data System
- INSPIRE: Infrastructure for Spatial Information in Europe
- ISO: International Organization for Standardization
- KIT: Karlsruhe Institute of Technology
- KML: Keyhole Markup Language
- LCA: Life Cycle Assessment
- LCI: Life Cycle Inventory
- LCIA: Life Cycle Impact Assessment
- LoD: Level of Detail
- MEP: Mechanical Electrical Plumbing
- NIBS: National Institute of BUILDING Science
- NIST: National Institute of Standards and Technology
- OGC: Open Geospatial Consortium

- OSM: OpenStreeetMap
- OWL: Web Ontology Language
- PLM: Product Lifecycle Management
- RDF: Resource Description Framework
- SIG3D: Special Interest Group 3D of German Spatial Data Infrastructure
- SPF: STEP Physical File
- STEP: Standard for the Exchange of Product model data
- STREAMER: Semantics-driven Design through Geo and Building Information Modelling for Energy-efficient Buildings Integrated in Mixed-use Healthcare Districts
- TNO: Netherlands Organisation for Applied Scientific Research
- UML: Unified Modeling Language
- URI: Uniform Resource Identifier
- V-Con: Virtual Construction for Roads
- VDA-FS: Verband der Automobilindustrie – Flächenschnittstelle
- VRML: Virtual Reality Modeling Language
- WWW: World Wide Web
- XML: Extensible Markup Language
- XSD: XML Schema Definition
- XSLT: Extensible Stylesheet Language Transformation

Definitions

Entity – A class of information defined by common properties [ISO10303-11].

Feature – A feature is an abstraction of real world phenomena [ISO19101-1].

Level of Detail (CityGML) – In computer graphics, the level of detail describes the complexity of the representation of a 3D object. Beside the geometrical complexity of the object, CityGML introduces different semantic levels for each level of detail [CityGML2012].

Life cycle assessment – Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [ISO14040].

Linked Data – In computing, linked data (often capitalized as Linked Data) describes a method of publishing structured data so that it can be interlinked and become more useful through semantic queries. It builds upon standard Web technologies such as HTTP, RDF and URIs, but rather than using them to serve web pages for human readers, it extends them to share information in a way that can be read automatically by computers. This enables data from different sources to be connected and queried [LinkedData2015].

Linked Open Data – Linked Open Data (LOD) is Linked Data, which is, released under an open licence, which does not impede its reuse for free [Berners-Lee2009].

openBIM – openBIM is a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows. openBIM is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model [bSI-vision2014].

STEP Physical File – A clear-text file format defined in the STandard for the Exchange of Product Data (STEP) and specified in the ISO 10303, part 21

Contents

1. Introduction

A central challenge of STREAMER is to organize an optimal collaboration of the different software tools involved in the design process. In this context, Task 6.3 “Interoperability of BIM and GIS design and energy data” deals with data interoperability among the three central thematic domains of STEAMER: “Building Information Modeling (BIM)”, “Geospatial Information Systems (GIS)”, and “Energy Simulation”. The central goal is to ensure that tools from different domains can read and write data from/to a common data base over the complete design process. This process is aggravated by the fact that different thematic domains use different modelling methods, data models and exchange standards.

This report is a central part of STREAMER deliverable D 6.5 “Advance mapping structures and standards”. It documents different approaches to and methods for solving interoperability issues, which are being developed or adapted under the STREAMER project. Furthermore, a number of domain-specific standards for data modelling, data exchange and user collaboration are reported and assessed for their STREAMER relevance. To prove their principle applicability, most of the approaches and methods reported here have already been implemented on a prototype level.

The report consists of four main parts:

- Standards for data modelling and data exchange;
- Advanced methods for mapping or integrating data from different domains;
- A summary of the actual mapping needs in the STREAMER project;
- Recommendations for using different standards and mapping methods in STREAMER.

In the central thematic domains of STREAMER a large number of official or de-facto modelling and data-exchange standards exist. Not all of them can be described exhaustively in this report. This presentation therefore concentrates on standards, which (1) simultaneously support technical, geometrical and semantical information, and (2) are relevant to the STEAMER project.

In chapter 2.1, the most important paradigms and languages for implementation independent, conceptual data modelling are presented. Different data exchange and collaboration standards from the BIM and GIS domains are introduced in chapters 2.2 and 2.3, respectively. In the last sections of chapter 2, standards for web-based access to GIS data (chapter 2.4.1 and 2.4.2) and BIM data (chapter 2.4.3) are mentioned.

Chapter 3 “Advanced mapping” deals with different methods for solving the interoperability issues. They can be structured into four categories:

- Data **Enriching** (chapter 3.1), provides missing information such as, e.g., a missing semantic classification of certain geometry objects, by a manual or (semi-) automatic processing step.
- A **Transformation** (chapter 3.2) automatically maps data from a specific initial format to a target format. Data transformations may be needed in case two software tools involved in the design process do not share a suited common interface format or when the amount of information involved in a specific modelling or evaluation process must be reduced for performance reasons.
- The **Integration** of data needs an application such as IFCExplorer (chapter 3.3). It is able to access data in different data models/formats via suited interfaces. Regardless of which interface format is used, the information has to be transferred to a uniform internal representation and a

common spatial context. This effectively supports common visualization and evaluation of data from different domains. A major challenge in this context is relating logically associated data from different sources, which could be performed on the basis of attributive information (e.g. a common object identifier) or spatial relationships.

- The **Linked Data** technique is a special method for connecting web-based data sets. With suited modelling languages such as the Ontology Web Language (OWL), logical associations between the data models of the involved data sets can be represented explicitly, enabling an integrated evaluation ("reasoning") of the linked data sets. A necessary prerequisite for this methodology is that the involved data sets and their corresponding data models/schemas are also represented in a suited ontology language such as OWL.

All methods and examples explained in chapter 3 focus on related activities of the STREAMER consortia. If necessary, references to activities or projects, which are not directly related to STREAMER partners, are given.

The methods described in chapter 3 at least are in a proof-of-concept stage and the benefits for STREAMER can be demonstrated. This leads to the final chapter 4, stating recommendations for the usage of standards and mapping methods in the project.

2. Standards for data modelling and exchange

A data model describes in an abstract manner how certain objects of the real world (e.g. existing or planned hospital buildings and their surrounding infrastructure) and their mutual relations are represented in an IT-system. All aspects of the real world object being relevant for the envisaged IT-applications have to be taken into account. For the application area of STREAMER these are, among others, the semantic meaning of an object, its geometrical shape and geographical position, and all relevant, e.g. energy-related, properties.

There are different methods and formal modelling languages for specifying data models (see 2.1). On the one hand there are graphically oriented languages like UML or EXPRESS-G, representing structure and content of a data model in an (at least for experts) easily understandable way. Purely textual representations like EXPRESS, OWL-RDF or XML-Schema are difficult to interpret by humans, but can much easier be processed by software. Therefore, they are often used to define an exchange format, describing the structure of the data model's instance documents. Applications may access instance data either locally, via file access, or remotely, e.g. via internet. Some important standards for the web-based access to spatially related data are mentioned in chapter 2.4.

Traditionally, the data models being used in different application domains have been developed independently. For the STREAMER projects, especially the application domains of Building Information Modeling (BIM) and Geospatial Information Systems (GIS) are relevant. The most important data models and exchange formats for these thematic areas are reviewed in chapters 2.2 and 2.3 respectively.

2.1 Modelling Languages

2.1.1 EXPRESS

EXPRESS is a textual language for representing data models. The development of EXPRESS started in 1984 with experiences of IGES (Initial Graphics Exchange Specification) [IGES2001] and some other efforts like VDA-FS (Verband der Automobilindustrie – Flächenschnittstelle) [VDAFS1987].

It is formalized in the International Organization for Standardization (ISO) Standard for Exchange of Product Models (STEP) [ISO10303-1] and standardized in ISO 10303-11 (EXPRESS language reference manual) [ISO10303-11]. STEP is developed and maintained by the Technical Committee TC 184 (Automation systems and integration), Sub-Committee SC 4 (Industrial data). This sub-committee develops standards, providing capabilities to describe and manage product data throughout the life of the product.

An EXRESS data model defines data objects and relations between these objects within a specific domain. Entities represent the general object type from which instances are generated. Entities can have both SUBTYPE and SUPERTYPE relations with other types. All attributes from a SUPERTYPE including DERIVED and INVERSE attributes, as well as WHERE clauses, are automatically inherited by a SUBTYPE.

The EXPRESS language is a block-structured programming language with a large set of programming constructs. Its main components are ENTITY, FUNCTION, PROCEDURE, RULE and SCHEMA, used for block declarations. A model can be defined by more than one SCHEMA, and cross schema references are possible. One of the advantages of EXPRESS is full procedural language syntax for specifying rules.

For the graphical representation of an EXPRESS schema, the EXPRESS-G graphical notation was developed. It is a subset of EXPRESS, defining diagrams for entity and type definitions, relations und cardinalities. EXPRESS-G is an integral part of the EXPRESS Language Reference Manual (ISO 10303-11) and defined in Annex B.

In addition there are some more extensions to EXPRESS. One is EXPRESS-C, which is an object-oriented and upward compatible extension of the EXPRESS language for conceptual modelling. It is used to model the behavioural aspects of data and related processes. Another extension is EXPRESS-X, defining a language to enable structural data mapping between two different data models.

Two distinct text encoding mechanisms are defined for exchanging and persistently storing EXPRESS data. Most widely used is the definition of ISO 10303 part 21, the STEP Physical File (SPF) or p21 file. It is a plain text ASCII encoding, representing all relations in a very compact way. The file is split into two sections: a header section containing meta information, and a data section containing the application data in accordance with a specific express schema. The second encoding mechanism represents EXPRESS in Extensible Markup Language (XML) format. The technical details are specified in ISO 10303-28, defining the XML-representation of EXPRESS data by Document Type Definitions (DTD) and XML-schemas.

2.1.2 **Unified Modeling Language (UML)**

The Unified Modeling Language (UML) is a very general, graphics-oriented modelling language in the area of software– and system engineering. Since the year 2000, UML is an official ISO standard. UML especially standardizes the visualization of complex system designs by defining a number of diagram types. For the specification of data models, especially the class diagram is used, representing the object structure by means of UML-elements with attributes and associations.

UML-based data models are frequently used to represent GIS data. In the context of STREAMER, this kind of data will be used to model the neighbourhood of newly planned or retrofitted hospital buildings. This may comprise the existing buildings on the hospital site, traffic infrastructure, and information on utility networks (e.g. electricity, water, district heating). For GIS data an ISO norm (ISO 19136 [ISO 19136]) exists, which defines a specialised UML-structure and a set of transformation rules. By applying this norm, it is possible to automatically generate a GML-based exchange format from the UML model.

2.1.3 **Semantic Web, Ontologies**

The Semantic Web is an important concept for the advancement of the World Wide Web (WWW). Actually, the content of the WWW is mostly represented in natural language. Therefore, an automatic processing of Web content by IT systems is more or less impossible. The advancement of the WWW to Semantic Web is mainly concerned with technologies enabling the automated interpretation and processing of Web content. Furthermore, it shall be possible in future to automatically relate associated information (Semantic Net). For this, the central challenge is to formally structure Web content and to associate it with an explicit meaning (semantics).

For this purpose, Semantic Web mainly applies knowledge representation concepts. Ontologies are a crucial technique to formally describe the objects of a certain knowledge domain. An ontology normally defines a number of concepts and a set of rules, logically relating concepts to an ontological network. By means of formal logic, this system supports automatic reasoning. For the specification of ontologies, a number of standardized languages exist. Most relevant for the domain of the STREAMER project are Resource Description Framework (RDF) and its follower Web Ontology Language (OWL).

OWL is often represented in forms of triples (Subject, Predicate and Object), which are held in Triple Stores, either in-memory or in an external database. These Triple Stores can be accessed with Query Languages like SPARQL, or submitted to semantic reasoners like FaCT++ or Hermit. For persistently storing OWL data sets, there are several formats available for serializing OWL like OWL/XML, RDF/XML, Turtle, etc. Editors like Protegé can be used to generate Ontologies in those formats, submit them to Semantic Reasoners and query the ontology. More details about Semantic Web and ontologies are available in the STREAMER deliverable D5.1.

2.1.4 XML-Schema Definition (XSD)

XSD (XML Schema Definition) is a recommendation of the World Wide Web Consortium (W3C). An XSD-document (often denoted as XML-Schema) enables to formally describe the hierarchical structure of Extensible Markup Language (XML) documents. The XSD document itself uses the XML syntax and supports, unlike other description languages for XML formats like Document Type Definition (DTD), not only a set of rules, but also specific data types.

If XML is used as basic syntax of a textually represented data model, a corresponding XML-Schema can be used to check the syntactical correctness of instance documents. For this purpose, a large number of software tools is available.

2.2 BIM Standards

2.2.1 Industry Foundation Classes (IFC)

The Industry Foundation Classes [ISO16739] are an open standard for BIM, developed by buildingSMART [bSI2014]. It is based on STEP [ISO10303-1] and the standardized data modelling language for product modelling EXPRESS [ISO10303-11], representing an entity-relationship model [Eastman1999]. Since version IFC4, it is an official international ISO standard [ISO16739].

Different file formats can be used for IFC. Most widely used is IFC-SPF based on STEP part 21. With IFC-XML based on STEP part 28 an XML encoding of the IFC data is available. In addition, a compressed file format with IFC-ZIP is defined consisting of an embedded IFC-SPF or IFC-XML file. In addition, there are different IFC-OWL definitions, which are not standardized, and therefore not further discussed in this document (see STREAMER deliverable D5.1).

The older, but still most frequently used version IFC2x3 contains 653 entities, covering all phases of a building's life cycle. For Architecture, Engineering and Construction (AEC) modelling aspects, IFC normally uses solid geometry for geometrically representing physical building elements. This can be a parametric representation (e.g. extrusion of a parametric profile), a Constructive Solid Geometry (CSG) or a boundary representation (BRep). IFC uses local Cartesian coordinates. For the root element of an IFC model (IFCSITE), optionally a global geographic location can be specified. One or more buildings and building complexes (IFCBUILDING) can be represented with their complete building structure, including storeys (IFCBUILDINGSTOREY), physical building elements (IFCBUILDINGELEMENT) and spaces (IFCSPACE) (see Figure 2). The physical building elements are represented as objects with relations to other objects. Such relations can be used, e.g., for addressing material information, properties or connections between building elements. A detailed IFC model of a demolished abbey including spaces and some interior equipment like furniture is shown in Figure 1.

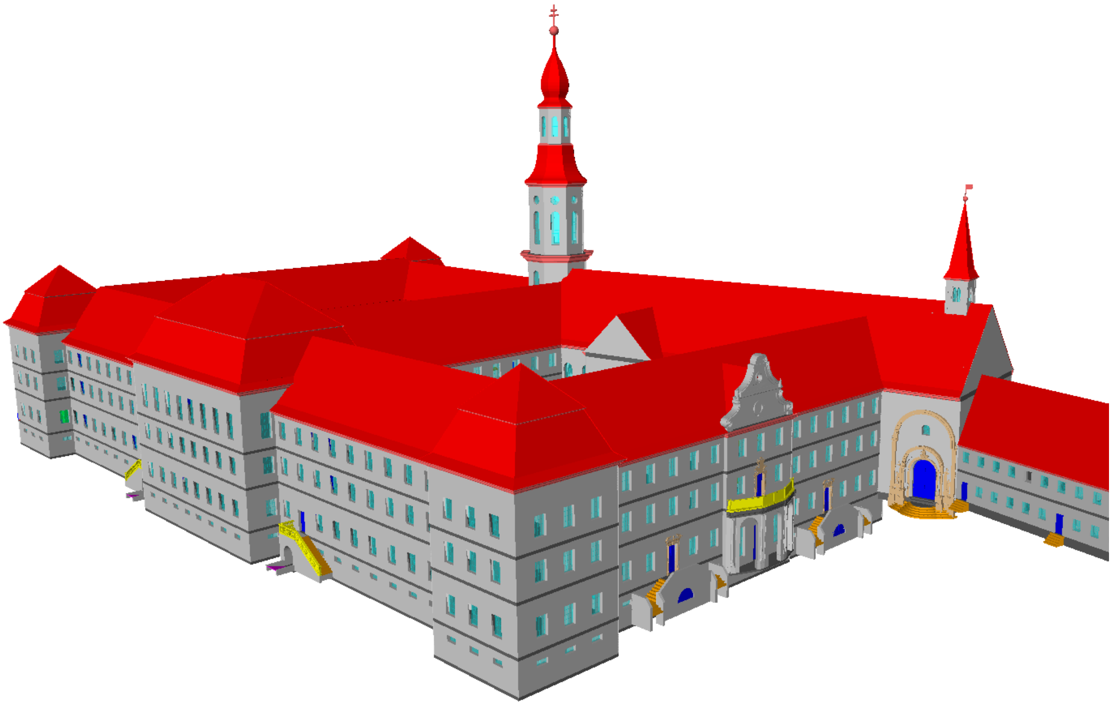

Figure 1: Detailed IFC model of an old abbey (source: KIT)

The implementations of IFC always focus on a specific purpose. For such a purpose, a Model View Definition (MVD) can be defined. A MVD is a subset of the IFC schema, which is needed to satisfy one or many Exchange Requirements (ER). The method used to define an ER is the Information Delivery Manual (IDM), specified in ISO 29481.
Currently, the most frequently implemented view definition is the Coordination View. It aims at the coordination between the major disciplines of architecture, structural engineering and building services during the design phase. In order to ensure a certain data quality, the buildingSMART certification program has been initiated. The ongoing certification process for Coordination View 2.0 includes more than 30 companies with over 35 applications [Hausknecht2014].

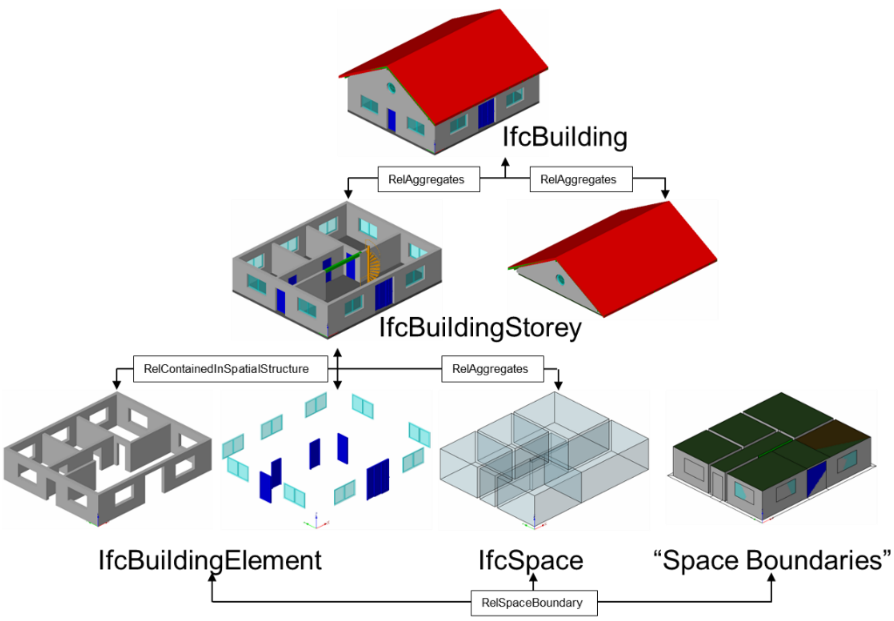

Figure 2: Basic IFC structure of a building (source: KIT)

Building Services

The specific entities for Heating, Ventilation and Air Conditioning (HVAC) are based on basic concepts defined for all building service elements such as plumbing, electrical, fire protection or building controls. These concepts include basic type and occurrence definitions for flow and distribution systems and fundamental properties used in building service scenarios, as well as performance characteristics. Especially for building service components the usage of type definitions it essential. Therefore, IFC support a generic/specific occurrence-modelling paradigm. This means a generic type definition can be used by different occurrences of a specific component.
The basic components are [IFC2007]:

- Distribution Chamber: a formed volume used in a distribution system, such as a sump, trench or manhole.
- Energy Conversion Device: a building system's device that converts energy from one form into another such as a boiler, chiller, or a cooling coil.
- Flow Controller: a device that regulates flow within a distribution system, such as a valve in a piping system, a modulating damper in an air distribution system, or an electrical switch in an electrical distribution system.

- Flow Fitting: a device that is used to interconnect flow segments or other fittings within a distribution system, such as a tee in a ducted system that branches flow into two directions, or a junction box in an electrical distribution system.
- Flow Moving Device: a device that is used to produce a pressure differential in a distribution system, such as a pump, fan, or compressor.
- Flow Segment: a section of a distribution system, such as a duct, pipe, or conduit.
- Flow Storage Device: a device used for the temporary storage of a fluid (e.g. a liquid or gas in a tank) or electrical power (e.g., a battery).
- Flow Terminal: acts as a terminus or beginning element in a distribution system such as a ceiling register in a ducted air distribution system, a sink in a wastewater system, or a light fixture in an electrical lighting system.
- Flow Treatment Device: a device used to change the physical properties of the medium, such as an air, oil or water filter (used to remove particulates from the fluid), or a duct silencer (used to attenuate noise).

For all building services components, it is essential to know the topology of the systems. Therefore, distribution systems are available with connection elements (ports), their relations to components and flow directions.

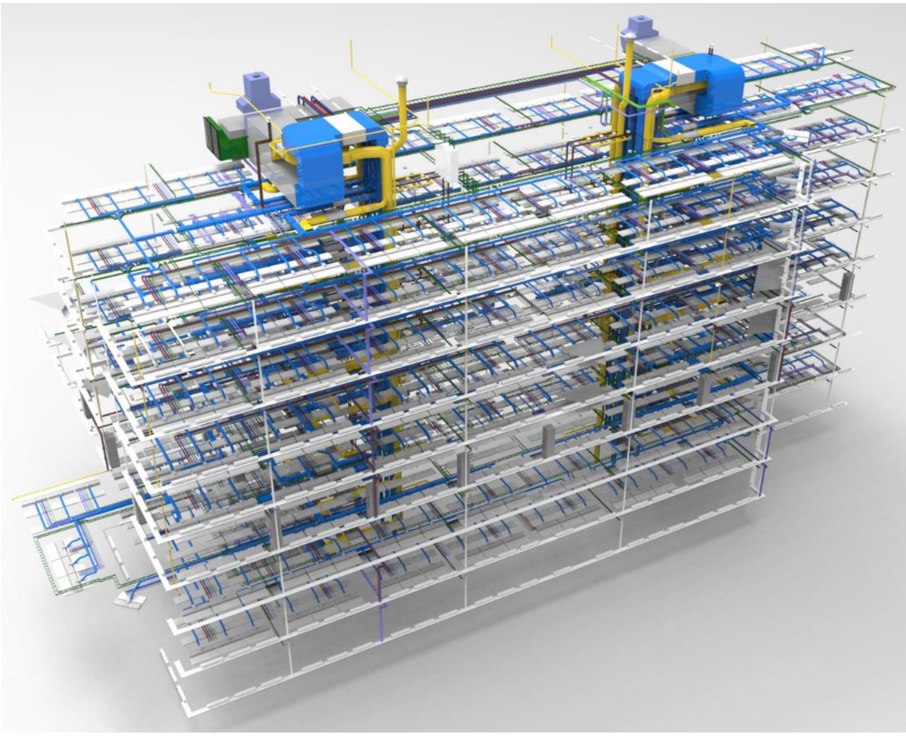

Figure 3: Example of a HVAC as IFC model (source: Data Design System)

Figure 3 conveys an imagination of 3D HVAC system of a complete building. The model is generated in DDS-CAD 10 [DDS-CAD2015] and then exported as IFC model.

Energy calculation

For many calculation and simulation purposes an abstract representation of the building shell and its spaces is required. These demands are defined as space boundaries in IFC and represented by the entity IFCRELSPACEBOUNDERY. It represents the connection surface between a physical component and a space. In this context also virtual connections are possible e.g. the resulting surfaces between two spaces or to the outside where a physical element is not available.

Two categories of space boundaries are defined:

- 1st level space boundaries: Representing the relation between a space and all surrounding building elements.
- 2nd level space boundaries: In addition to the surrounding building elements also the adjacent spaces are considered and the boundaries are mostly a subdivision of the first level boundaries (see Figure 4 right).

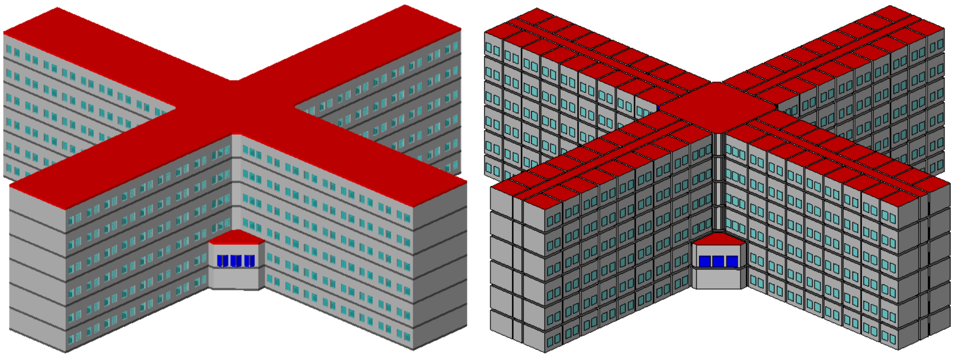

Figure 4: IFC model represented with building elements (left) and as space boundaries (right)

IFC4 Extensions

IFC4 is a major rework and improvement of the existing IFC specification. There are a lot of changes made to enhance the consistency in the IFC schema and to extend the functionality of entities, properties and quantities. Here only changes which could be relevant for the STREAMER project are reported.

A new feature of IFC4 is the possibility to specify a precise geo-reference of the model, defined by a map projection. In the previous version, it was only possible to specify the geographic location of an IFCSITE in terms of longitude and latitude values with limited precision. Also new in this context is IFCGEOGRAPHICELEMENT, which allows placing any globally geo-referenced object in the context of a site.

In addition to the already existing IFCZONE entity, a new spatial element IFCSPATIALZONE was introduced in IFC4.In contrast to IFCZONE, IFCSPATIALZONE allows an own placement and shape representation. Furthermore, the concept of space boundaries was extended. In IFC4, there is a clear differentiation between 1st and 2nd level space boundaries by the entities IFCRELSPACEBOUNDARY (1st Level) and IFCRELSPACEBOUNDARY (2nd Level). The identification of opening elements like doors or windows and the definition of external logical or physical regions are possible now.

Improvements are also made for the HVAC and electrical domains. The specific concepts of distribution systems are covered now by a specialization of IFCSYSTEM with various predefined types for heating, cooling, ventilation, plumping, security, and electrical systems. In this context, also the ports are improved to support an assignment to manufacturer types and nesting relationships. Specific to electrical equipment the support for protective devices including separation of tripping and breaker units was added.

In addition, changes were made to clarify and enhance property sets, including multi-lingual support.

Relevance for STREAMER

As an integrated building model, supporting the complete life cycle IFC is of high relevance for STREAMER. No other data model has the capabilities to support especially the design/construction processes. In addition, IFC allows a many possibilities in decomposing buildings (see Appendix 6.3), which might be relevant for create functional models as described in STREAMER Deliverable 1.1 [D1-1-2014].

Different domains (BIM and GIS), data availability and interoperability issues of the required software application will lead to processes where IFC data have to be converted into or linked with other data models. Nevertheless, within the STREAMER PLM architecture the IFC model will play the most important role in the life cycle.

2.2.2 BIM Collaboration Format (BCF)

As there are many actors being involved in a planning process, the support of communication and collaboration processes is vital. The BIM Collaboration Format (BCF) supports both, without losing the link to the building information model. BCF is an open file format promoted by buildingSMART for enabling workflow communication between different BIM applications [bSI-BCF-2014]. Each topic of the communication can be linked to an IFC entity by referring to its global unique identifier (GUID). The format is based on XML and consists for each BCF topic of several files [Linhard2015]:

- project.bcfp (Version 2.0 optional)
- markup.bcf (Version 1.0 and 2.0)
- viewpoint.bcfv (Version 1.0 and 2.0)
- snapshot.png (Version 1.0 and 2.0)
- Attached documents (Version 2.0)
- BIM-Snippets (Version 2.0)

The project file (project.bcfp) includes reference information about the project the topics belong to. In the mark-up file (markup.bcf) all textual information about the topic, like status, date, author and the comment itself, is available (see Figure 5). Since version 2.0 of BCF, multiple viewpoints and snapshots (viewpoint.bcfv, snapshot.png) are supported. Viewpoint files contain all information to create a virtual camera in order to focus on the entity, which is marked-up. The virtual camera can simulate either a perspective or an orthographic projection. Furthermore, it is possible to define clipping planes in order to control the viewing space of the camera. Beside the virtual camera, snapshots can illustrate the mark-ups. With version 2.0, it is possible to attach documents or BIM snippets. Both can be either stored in the BCF zip file (*.bcfzip) or can be an externally referenced (url).

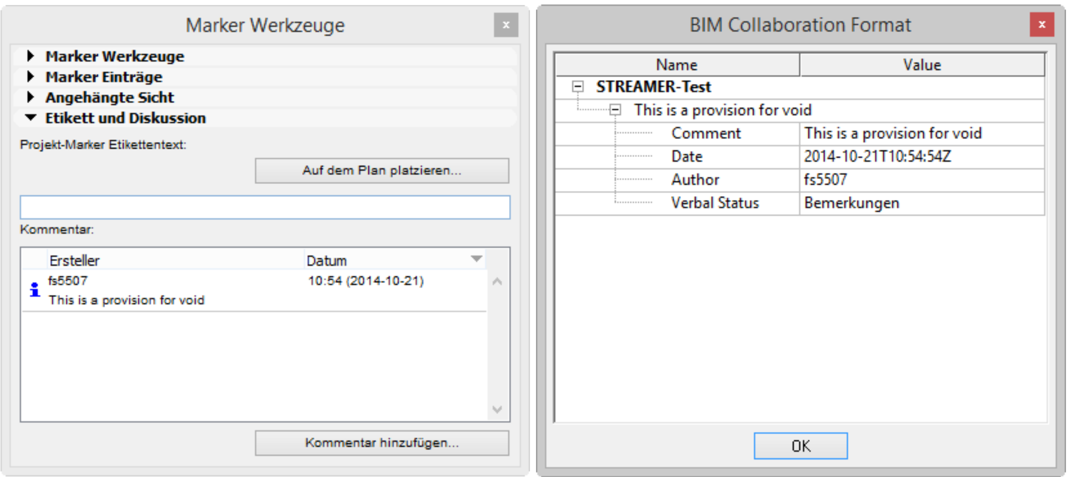

*Figure 5: Model mark-up in ArchiCAD 18 **[ArchiCAD2014]** (left) and the corresponding BCF import in the IFCExplorer [Benner2013] (markup.bcf)*

The collaboration based on the BCF format can be carried out in two ways:

- File based;
- Via web services.

In the first case, a application is importing an IFC model and the user defines mark-ups, optionally including snapshots, for each issue regarding the model (e.g. clashes, design changes, questions). Then the mark-ups will be saved as a BCF file (*.bcfzip). The BCF file will be sent to the responsible actor, who will import the file into the originating application. After the issues have been solved, the status of the issues can be changed and sent back for acknowledgement.

In the second way to use BCF, ideally both the IFC model and the BCF files are stored in a database, which usually is realized via web services. By managing the database access, the distribution of the issues can be automated, controlled and logged. In order to specify suited web services, with version BCF 2.0 a first RESTful specification was proposed by the company DDS and provided to buildingSMART. The BCF 2.0 RESTful API [BCF-API2014] standardizes the web service to exchange BCF topics, including the management of user rights and roles [Linhard2015].

Figure 6 shows a mark-up originally created in the CAAD System ArchiCAD and then imported into the IFCExplorer, the DDS-CAD Viewer, REVIT (using an Add-In), Solibri and BIMSight.

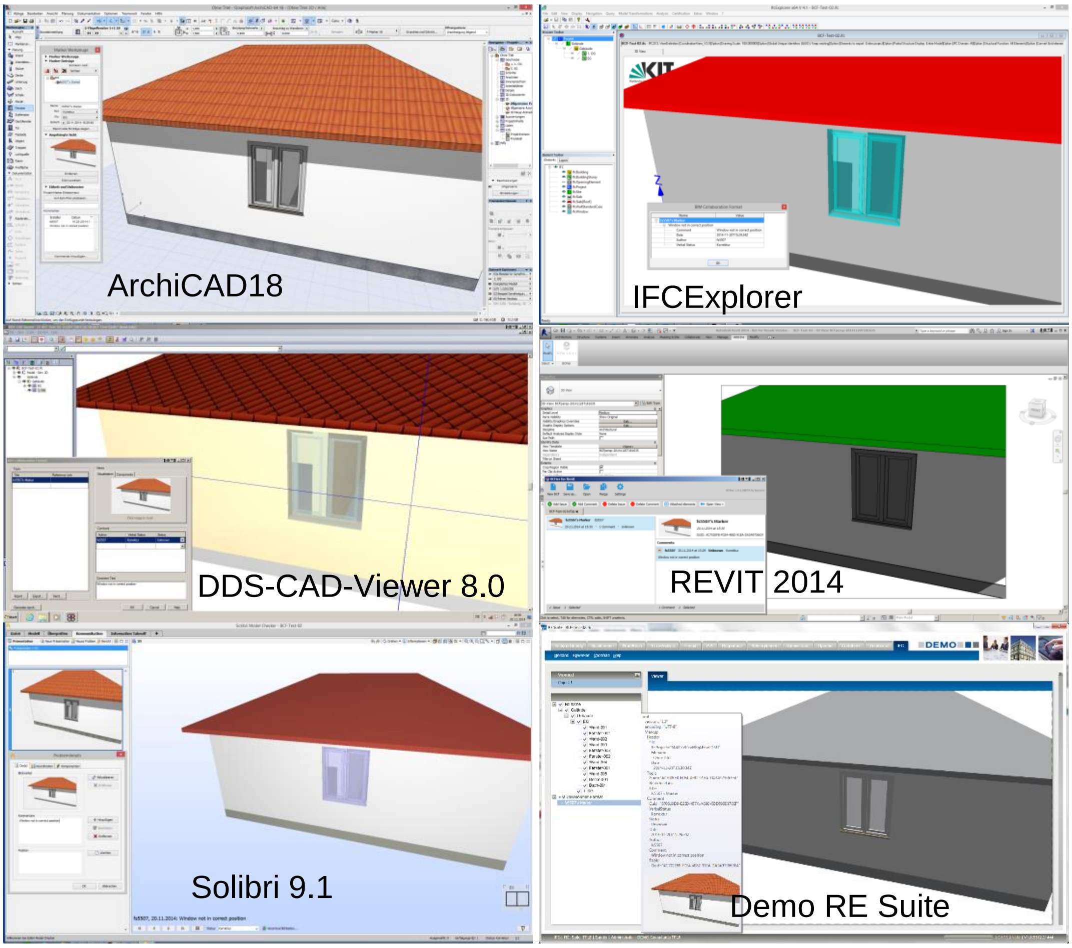

*Figure 6: Original mark-up in ArchiCAD 18 **[ArchiCAD2014]** (upper left) and the corresponding IFC model and BCF file in the IFCExplorer **[Benner2013]** (upper right), DDS-CAD Viewer 8.0 middle left), REVIT2014 with BCFier [BCFier2014] Add-In (middle right), Solibri 9.1 (lower left) and Demo RE Suite (lower right)*

Relevance for STREAMER

Within STREAMER the BCF format will be an appropriate way to collaborate within the openBIM (IFC) environment. For managing the communication and collaborating via web services, the "Product Lifecycle Management" (PLM) system (a deliverable of work package 5) must cover all aspects regarding e.g. distribution, documentation, data history, safety and security.

2.2.3 Green Building XML (gbXML)

Green Building XML (gbXML) is an open [OpenFormat2015], XML based data exchange format. Its main purpose is to facilitate the transfer of building properties between 3D BIM and engineering analysis tools. gbXML is supported by leading 3D BIM vendors (e. g. Autodesk, Bentley, Graphisoft) and can be processed by major engineering analysis tools (e.g. EnergyPlus and TRNSYS). Thus, it has become the de-facto industry standard schema in this area [gbXML2014]. The model covers all major aspects for energy and performance simulations, which are the building geometry, the HVAC design, the internal and external environmental influences and the representation of simulation results. Figure 7 depicts the building geometry of a typical gbXML model.

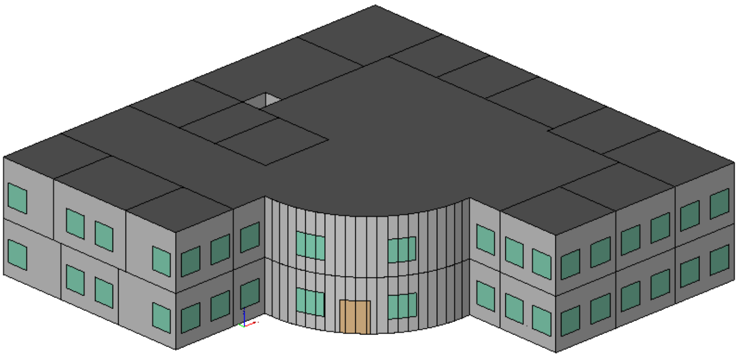

Figure 7: Example of the gbXML representation of an office building (33 Spaces, 174 wall surfaces, 36 doors and 72 windows) (source: http://www.gbxml.org/samplegbxmlfiles.php)

Building model

The gbXML Campus object is the base for all physical objects in the model. The Campus can refer to one or more gbXML Building objects and an arbitrary number of Surface objects (surface type: ExteriorWall, Roof, Shade, Ceiling etc.). A Building can have, among others, a geometrical representation of the exterior shell (ShellGeometry) and relations to spaces (gbXML class Space). Space objects can be grouped horizontally by assigning them to a BuildingStorey object. In addition, Spaces can be assigned to Zones [USPatent2004].

A Surface object represents the thermal boundary of a Space and can be modelled both by RectangularGeometry (origin, width, height and orientation) and by PlanarGeometry (polygons). By establishing relations between Surface objects and one (in case of an exterior surface) or two Space objects (in case of an interior surface), a Space is completely bounded by Surface objects. Figure 8 schematically depicts the structure of the gbXML building model.

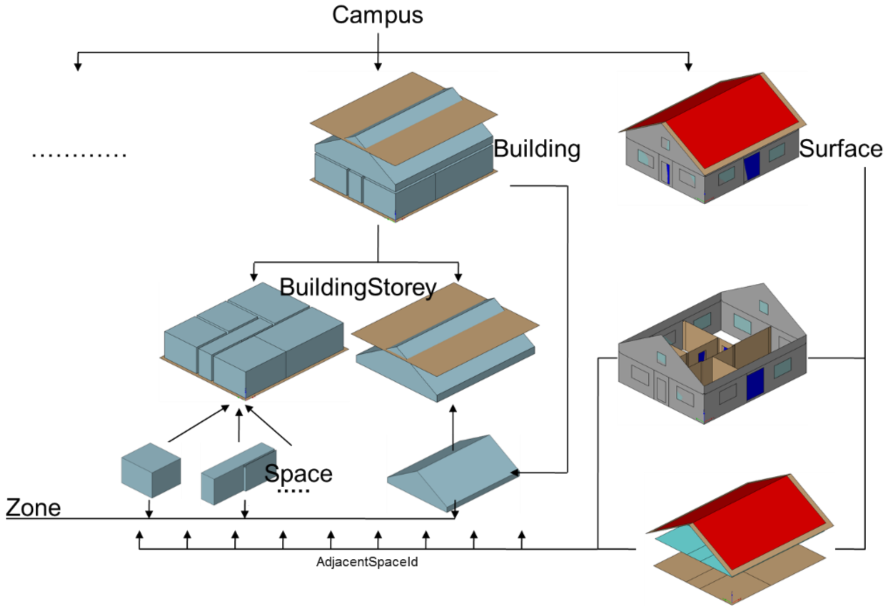

Figure 8: gbXML structure of the building model (source: KIT)

Beside the geometry and relations between BoundarySurfaces and Spaces, the gbXML building model contains all relevant information for energy performance simulations. Each BoundarySurface object can have a detailed description of its construction including multiple construction layers and all relevant construction and material properties (see chapter 6.2). Windows, which are important building elements for energy calculation, can be described in detail by modelled frames, gaps, glazing and blinds.

Besides different geometrical representations (floor area and volume), Spaces can carry information about the usage (e.g. space type, number of people, air change rate) and the contained equipment (e.g. lighting, generalized interior equipment).

Building Services

The equipment for building services is subdivided into following classes:

- interior and exterior equipment (classes IntEquip, ExtEquip),
- air and hydronic loop equipment (classes AirLoopEquipment, HydronicLoopEquipment),
- Lighting (class Lighting),
- and measurement devices (class Meter).

The interior and exterior equipment are generalized devices, e.g. refrigerator or photovoltaic, which usually do not belong to air or hydronic loop. Nevertheless, optionally, they can have a reference to an air or hydronic loop.

For the HVAC system, gbXML distinguish between air based systems (air loop) and water based systems (hydronic loop). According to the loop type, the systems are modelled with air loop equipment or with hydronic loop equipment. Control parameters of loop equipment, e.g. operationalType (Cycling or Continuous), can be described with the Control class. Figure 9 shows an example of one gbXML space having two hydronic loop equipment devices.

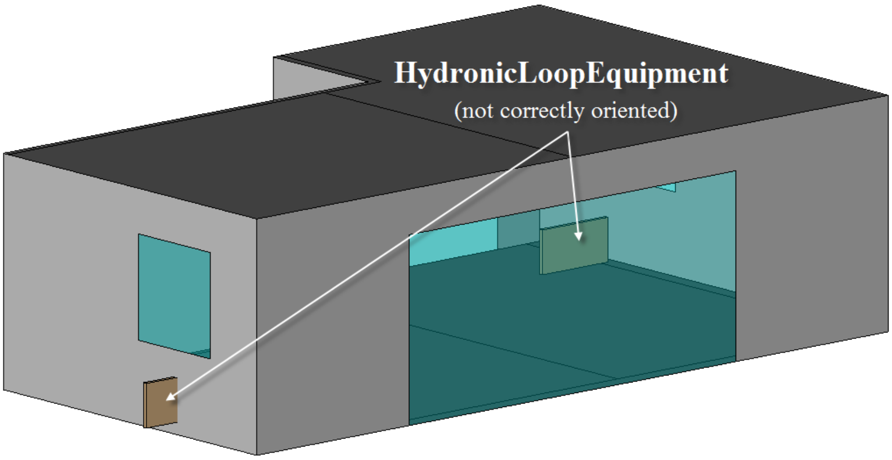

Figure 9: Example of two radiators (HydronicLoopEquipment) belonging to a gbXML space (created by Solar Computer GmbH / AutoCAD MEP)

A Lighting object can be assigned to Campus, Building or Space. Besides geometry, Lighting has a number of parameters in order to define different reflectance properties and the position of the light source. Lighting can refer to a lighting system (class LightingSystem) in which the types of lamp, manufacturer, input power etc. are specified.

Measurement devices can be modelled by the gbXML class Meter. The resourceType attribute of Meter specifies the measured quantity (e.g. electricity, gas, oil, water, steam). In addition, a meter can have an UtilityRate for the use of billing schemas.

Additional information

gbXML contains a number of resources to model general aspects needed for performance simulation:

- The global origin of the simulated physical object (Campus) can be specified by the elevation, longitude, and latitude values;
- The weather situation for a specific location can be described by a large number of parameters;
- The presence of people or the activities of equipment and systems can be modelled by using schedules;
- All kind of costs can be taken into account by applying the Cost element;
- Public transportation can be considered by causing additional costs;
- Vegetation can affect the performance by providing shade, consuming water and forming a biomass potential;
- The version of the originating system and the document history can be stored and can provide information of the document lifecycle.

Simulation results

Simulation results can be stored in a gbXML document by the gbXML element Results. Results can be applied at building and space level and can be a function of any period of time [USPatent2004]. The simulation results can be grouped into four categories:

- energy use and costs,
- thermal loads,
- equipment sizes and constructions,
- comfort measures [USPatent2004].

The energy use includes power for electricity and / or fuel. The energy costs can be specified regarding the geographic location of the campus. Thermal loads (e.g. heating and cooling loads, temperature, airflow) can be determined for each component in the building separately. In order to design the equipment and the complete systems (air loop, hydronic loop) results like heating and cooling capacities can be assigned to the building and / or to the air and hydronic loops. Finally, monthly minimum, maximum, average temperature and humidity can be assigned to single spaces.

Relevance for STREAMER

gbXML has been designed for performances analysis and therefore is supported by all major simulation applications. In the STREAMER context, it might be used to bridge the gap between the design models and the energy simulation and decision support systems, as an alternative to IFC.

2.2.4 VDI3805 / ISO/DIS 16757-1

VDI3805 is a guideline for the exchange of product data in computer-aided planning processes within the domain of building services (HVAC). The guideline covers all relevant manufacturer-specific product information for the planning and the technical design of systems for building services.

Products are represented in VDI3805 as electronic catalogues. This means a product (e.g. a boiler) is usually described by parameters, which allows the user to select all possible variants of the product (e.g. size, connects). In addition, a product can have links to all possible accessories.

The product information contains four categories of data:

- Product identification data, like product description, grouping and classification;
- Technical data for the design and calculation in numerical form, like characteristic curve field, calculation formulas and algorithms for the design of the product;
- Geometry data for describing the shape of the product including disturbance spaces and connecting data, like plans, drawings, sections and 3D representations;
- Picture data for visual information, like photographs, symbols or schematic representations.

As the VDI3805 contains all possible variants of the product, software is needed to select a suited variant of the product, which fulfils the requirement of the user. Examples for such applications are the VDI3805-Navigator from the Hottgenroth Software GmbH [Hottgenroth2014] and the TROX Easy Product Finder [TROX2012].

The VDI3805-Navigator is a product independent application for selecting HVAC products. Depending on the catalogues loaded, the user can select the products like heat generator, radiator, pumps or valves. In Figure 10 (left), the selected heat generator is shown as a 3D model including all accessories and connection ports. In addition, the disturbance space, which is need for installation and maintenance, can be visualized. The left side of the figure shows information about the dimensioning of the product. This can cover data for the product characteristics, performance data, environmentally relevant data and control data.

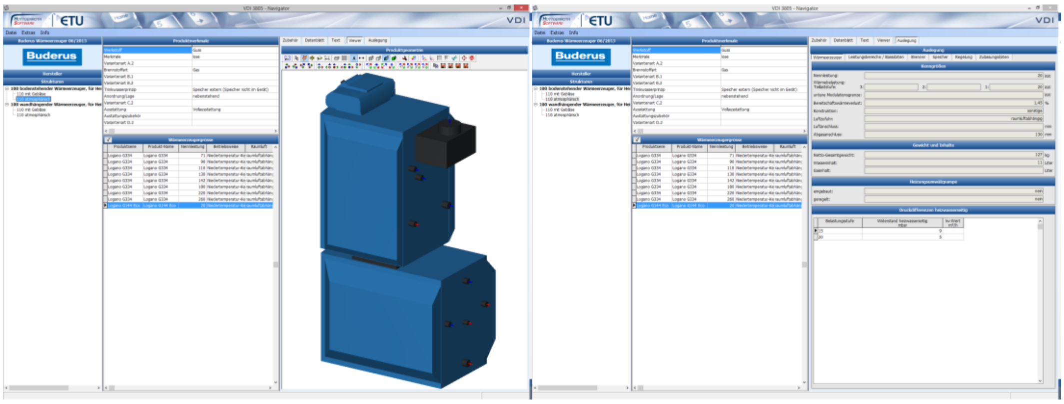

Figure 10: Example of a heat generator in the VDI3805-Navigator (left: the 3D model including connection information, right: dimensioning information)

Figure 11 shows the TROX Easy Product Finder. All major products from the company TROX can be found in this electronic catalogue. In the shown example, the category “fire protection flaps” was chosen. After specifying the type and dimension of the fire protection flap, all information such as flow rate, weight, or pressure loss are available (Figure 11 left). In addition to this information, a 3D model of the specific product including connection data (e.g. flow direction) can be generated (Figure 11 right).

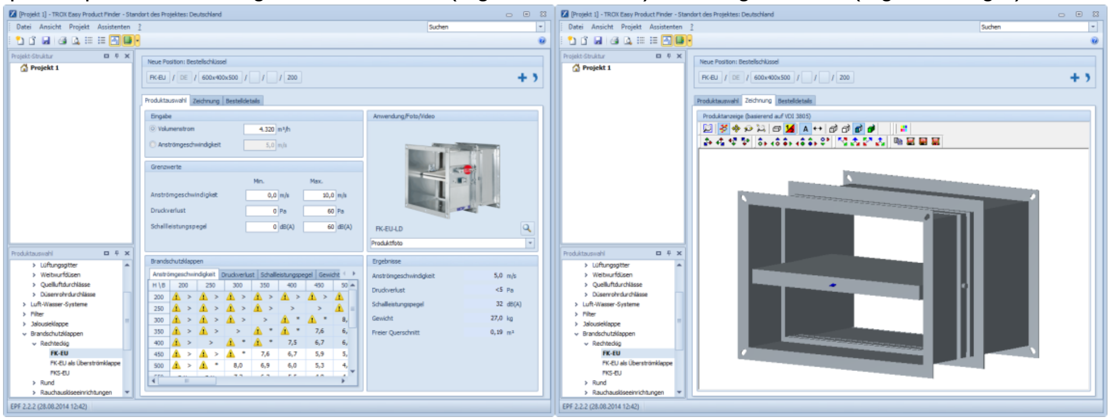

Figure 11: Selection of a fire protection flap from a catalogue based on VDI3805 [TROX2012]

After selecting a specific product, there are two ways for further processing:

- The application for planning the building services can directly import VDI3805 data, like Data Design System [DDS2014]
- The application is able to convert the data into other formats, like IFC or DXF. As these data models or formats cannot represent all VDI3805 information, only a subset of this information might be available in downstream applications.

Currently the VDI3805 guideline is proposed to ISO. In a subcommittee of “Building and civil engineering works” the ISO 16757-1 standard “Data structures for electronic product catalogues for building services – Part 1: Concepts, architecture and model” is under development [ISO/DIS 16757-1].

Relevance for STREAMER

As a national German guideline, the VDI3805 will not be involved in the STREAMER project. The international standard ISO 16757-1 standard is under development and not yet available.

2.2.5 International Reference Life Cycle Data System (ILCD) data format

For sustainable building s, it is not enough to consider energy consumption only during the operational phase, but also to consider the energy efficiency and environmental impacts during the whole life cycle.

In particular, the production / construction phase and the demolition / re-use phase strongly affect sustainability.

In order to assess the impacts of buildings on the global environment, Life Cycle Assessment (LCA) methodologies are applied. Considering the ecological quality of buildings, building material and building components play a substantial role in LCA [Düpmeier2014]. As LCA needs reliable and consistent data and methods, the European Commission is promoting and supporting the use of life cycle data and tools through its European Platform on LCA [LCA2014]. One aim of this platform is to provide consistent and quality-assured Life Cycle Inventory (LCI) data sets. As reference format and for data exchange of LCI data sets, the International Reference Life Cycle Data System (ILCD) data format was specified. The ILCD data format has been released in 2009 and is a further development of the former European Reference Life Cycle Database (ELCD) format.

ILCD Data Format

The ILCD data format is implemented in XML and based on a number of linked data sets [ILCD2014]. Instead of a single data set, the ILCAD format facilitates seven data set types which indicate different semantic concepts in LCA modelling and which are linked by global references. Currently, the following data set types are available [Wolf2011]:

- "Process for modelling both unit and aggregated processes and result sets. Input and output flows are modelled by global references to other data sets of type Flow. Process data sets may optionally contain results of an impact assessment; in this case data sets of type LCIA Method will be referenced in a result list."
- "Flow describes an elementary, product or waste flow. It references one or more Flow Property data sets."
- "Flow Property (quantity) describes physical or other properties of a flow that can be used to quantify it, for example mass or gross calorific value. Each instance references one Unit Group data set."
- "Unit Group (dimension) describes a group of convertible units and the conversion factors to its reference unit."
- "LCIA Method describes an LCIA method and its characterization factors e.g. an impact category like global warming potential or Eco toxicity. The data set can also document an entire LCIA methodology. The data set references one Flow Property data set that identifies the quantity of the characterization factors and - via the further reference to the Unit group - their dimension."
- "Source represents an external source of information, such as literature or a database or data format. It can contain a reference to an external file or resource as well. It can reference a contact it is related to."
- "Contact describes a person or organization. It can itself again reference another contact, allowing to document hierarchical relationships (e.g. person - working group - organization)."

The linked data approach reduces redundancies and makes the maintenance and updating of the data sets more effective. Figure 12 shows the relation between the different data sets [Wolf2011].

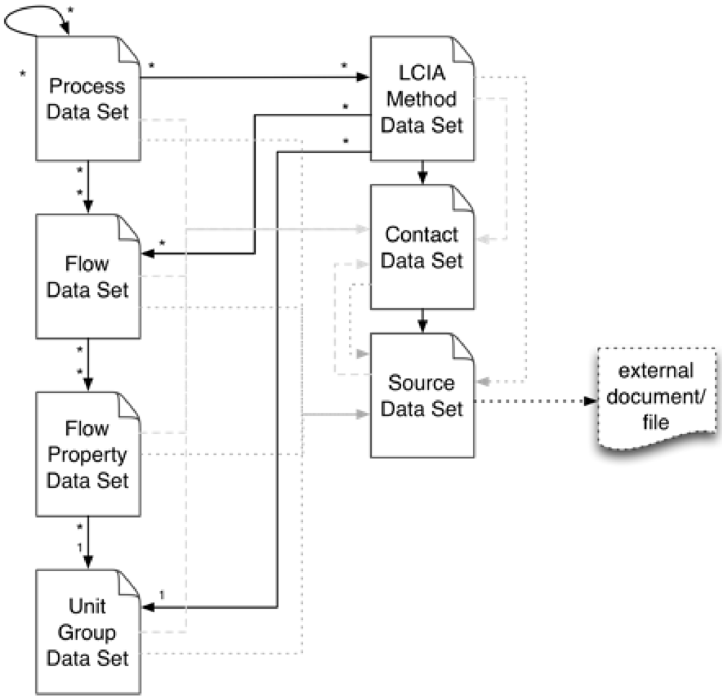

Figure 12: ILCD data set types and their relationships [Wolf2011]

Examples

The European reference Life Cycle Database (ELCD) contains LCI data from different sources for materials, energy carriers, transport, and waste management. Figure 13 shows the overview page of the process data set for “Aerated concrete block” (can be accessed via http://eplca.jrc.ec.europa.eu/ELCD3/showProcess.xhtml?uuid=898618b5-3306-11dd-bd11-0800200c9a66&version=03.00.000). On this web page, the XML ILCD format is converted in HTML via XSLT stylesheets. The full data set can be shown in HTML or the original XML file can be downloaded.

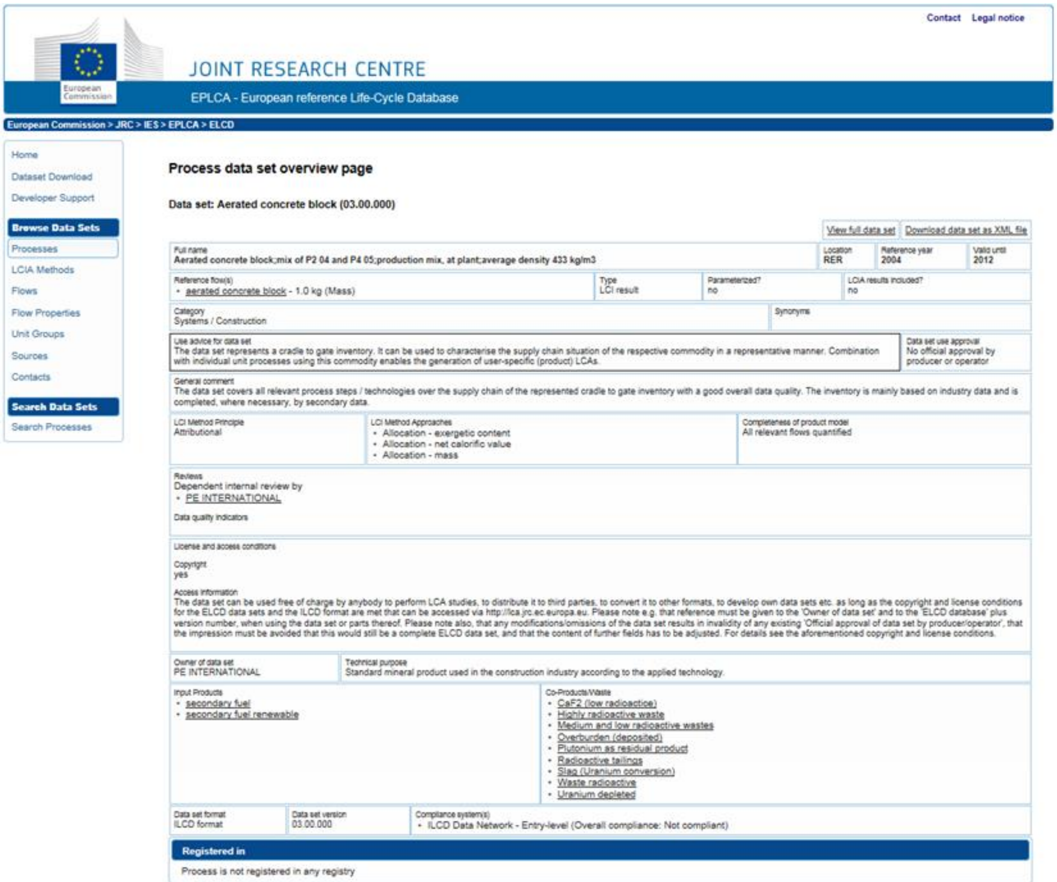

Figure 13: Process data set overview page for “Aerated concrete block”

Relevance for STREAMER

If considering the complete life cycle of buildings regarding sustainability and energy efficiency, LCI data are essential. For STREAMER, as a EUROPEAN wide project with demonstration sites in France, Italy, Netherlands and United Kingdom, standardized LCI data are important for the benchmarking. National approaches for LCI data, e.g. Ökobau.dat in Germany [Brockmann2014], might be difficult to compare and might cause inconsistencies in the overall benchmarking.

2.3 GIS Standards

2.3.1 City Geography Markup Language (CityGML)

The City Geography Markup Language (CityGML) of the Open Geospatial Consortium (OGC) is an open data model for the storage and exchange of virtual 3D city models [CityGML2012]. CityGML 2.0 is a XML based format and an application schema for the Geography Markup Language (GML) version 3.1.1 [GML2004].

The standard is subdivided into several modules. Beside the Core module, 13 thematic extension modules are available in CityGML 2.0: Appearance, Bridge, Building, CityFurniture, CityObjectGroup, Generics, LandUse, Relief, Transportation, Tunnel, Vegetation, WaterBody and TexturedSurface.

In order to model real-world features like buildings, roads and vegetation on different scales, CityGML includes a Level of Detail (LoD) concept. This LoD concept not only refines the geometry of a feature with increasing levels, but also the semantic modelling depth. Figure 14 shows a CityGML model of

Careggi hospital with buildings modelled in LoD1, and a model of Rijnstate hospital with LoD2 buildings. In both cases, roads are modelled in LoD 0.

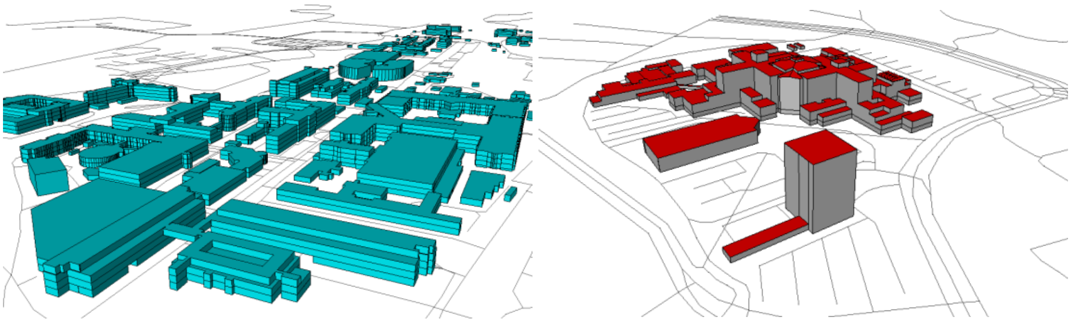

Figure 14: CityGML model of Careggi hospital (left: buildings modelled in LoD 1, roads modelled in LoD 0) and Rijnstate hospital (right: buildings modelled in LoD 2, roads modelled in LoD 0)

Building module

The building module is the most frequently used CityGML module, defining all features, which are necessary to model the building's exterior and interior. If required, a building (CityGML feature type Building) can be subdivided into building parts (feature type BuildingPart). In the lower level of detail (LoD 0 and LoD 1), no further semantic structuring of Building or Buildingpart is possible. Starting from LoD2, exterior boundary surfaces like walls (WallSurface) or roofs (RoofSurface), and outer building installation (BuildingInstallation) such as chimneys or balconies, can be represented separately. Finally, in the highest Level of Detail (LoD4), also the representation of interior building structures is possible. Figure 15 gives a brief overview of the CityGML Building structure.

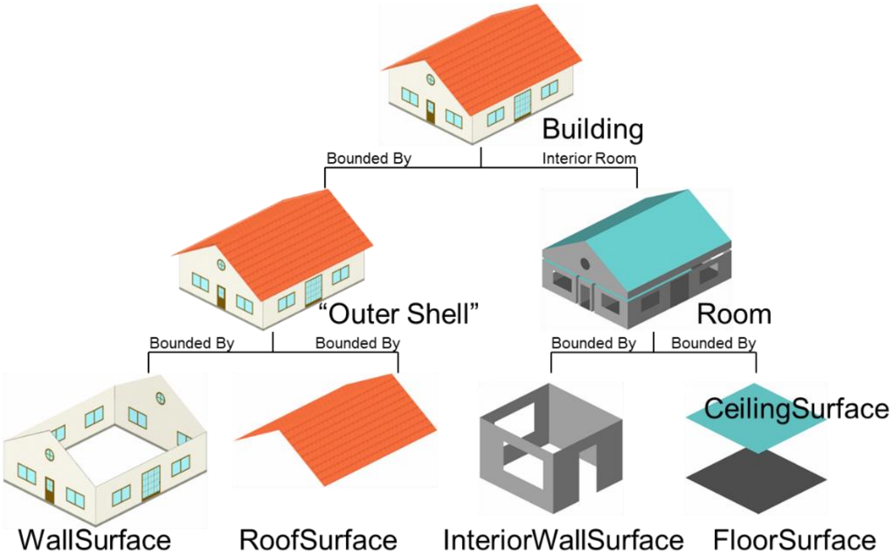

Figure 15: Basic structure of a CityGML building (source: KIT)

As a general-purpose data model, CityGML currently offers no specific energy related features or properties for buildings. Nevertheless, some concepts and attributes may be useful for energy simulations or estimations:

- The geometric representation of a building as solid enables the calculation of the building volume.

- Due to the usage of global geographic coordinates, CityGML building models have a correct real-world position and orientation. Thus, building orientation effects or the influence of neighbouring structures can be taken into account.
- A number of attributes can be used to estimate the building size and its energetic quality:
    - Number of storeys, optionally including storey heights,
    - Year of construction, function and usage of the building;
- The classification of the building's exterior shell by different kinds of boundary surfaces (e.g. roof or wall surfaces);
- Interior building installations, e.g. heat generator or radiator, geometrically represent building services.

Transportation Objects

The transportation module covers all kinds of traffic infrastructure except bridges, tunnels and waterways, which are modelled in separate modules. The main feature TransportationComplex represents for example roads or railways. The representation of a TransportationComplex starts with the Level of Detail 0 modelling of a linear network. With LoD 1 the TransportationComplex provides surface geometry. In the higher Levels of Detail (LoD 2, LoD 3 and LoD 4) the TransportationComplex can be further subdivided into TrafficArea (e.g. driving lanes, bicycle line or pedestrian zones) and AuxiliaryTrafficArea (e.g. kerbstones or green areas) [CityGML2012].

As traffic is an important aspect in the overall energy examination, the transportation objects have to be taken into consideration. Even if the LoD 0 representation is geometrically forming a linear network, the routing from for example a hospital building to the next bus station has to be performed by the importing application. As there are no relations between buildings, city furniture (bus stop) and the road network, navigation might be difficult. An example of a road network, represented in LoD 0 is depicted in Figure 16 (left).

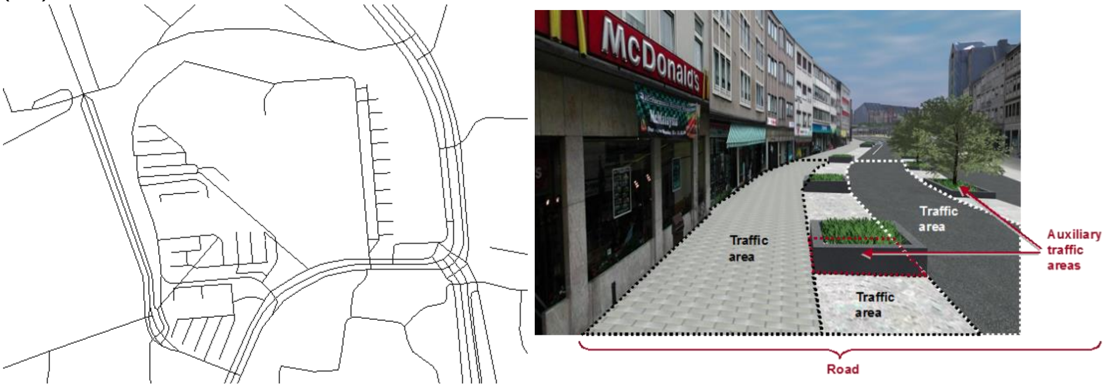

Figure 16: Roads of the Rijnstate hospital represented with LoD 0 geometry (left) and an example for a LoD 2 road, which is subdivided into different traffic areas (right) (source: City of Solingen, IGG Uni Bonn [CityGML2012])

Transportation objects represented in more detail are helpful to get a visual impression of the district. Figure 16 (right) shows an example, in which the road is subdivided into the driving lane, sidewalk and green areas. In order increase realism, the surfaces are textured.

Other Modules

All the other modules of CityGML version 2.0 have almost no influence on energy considerations. Bridges (Bridge module) and tunnels (Tunnel module) will probably not have a high significance when planning health care districts. The digital terrain model (Relief module) and water bodies (Water bodies module) might be important for the integration of the buildings into the landscape, but is not essential for energy simulation. The terrain model might be relevant for the simulation of microclimate aspects, but this is not a target of STREAMER. Vegetation objects (Vegetation module) might have an influence on energy as being shading objects. Other influencing factors of vegetation on the energy consumption will not be part of the STREAMER project.

The CityFurniture module with the only feature CityFurniture is used to model all other equipment of the city, like streetlamps, solar cells and windmills. The information content of this module is too low to be taken into account in any energy simulation.

The Landuse module is intended to describe human activities on the earth's surface and its physical and biological cover. The classification of land use is not sufficient for any detailed planning processes.

CityGML Application Domain Extension (ADE)

CityGML has not been designed to support a specific application area. In particular, the different feature classes only have very few non-geometrical properties. However, with the CityGML concept of Application Domain Extensions (ADE) it is possible to specify extensions of the standard. The ADE concept supports two different extension mechanisms: Defining new feature classes, which are derived from existing CityGML features, and extending the property set of existing CityGML feature classes. Both extension mechanisms may be relevant for STREAMER, in order to enrich existing CityGML building models with energy relevant information needed by simulation systems.

Currently there are two CityGML ADEs, which may be important for STREAMER:

- UtilityNetwork ADE [Becker2011]
- Energy ADE [Casper2014]

The UtilityNetwork ADE was developed to model infrastructures within cities. The ADE is subdivided into two parts, each part with a separate schema:

- Utility core,
- Utility network components.

The Utility core package is used to model the 3D topography of the network features. The network is based on a dual representation, modelling both the 3D topography and the complementary graph structure. Network hierarchies of arbitrary depth are supported on network object level and for the entire utility network.

The Utility network component packages defines a limited number of network components like pipes, fittings or valves. Figure 17 shows an example of four networks belong to a district heating system. The networks are represented both with a 3D topography (blue lines and points) and with 3D round pipe components (blue cylinders diameter 30 cm).

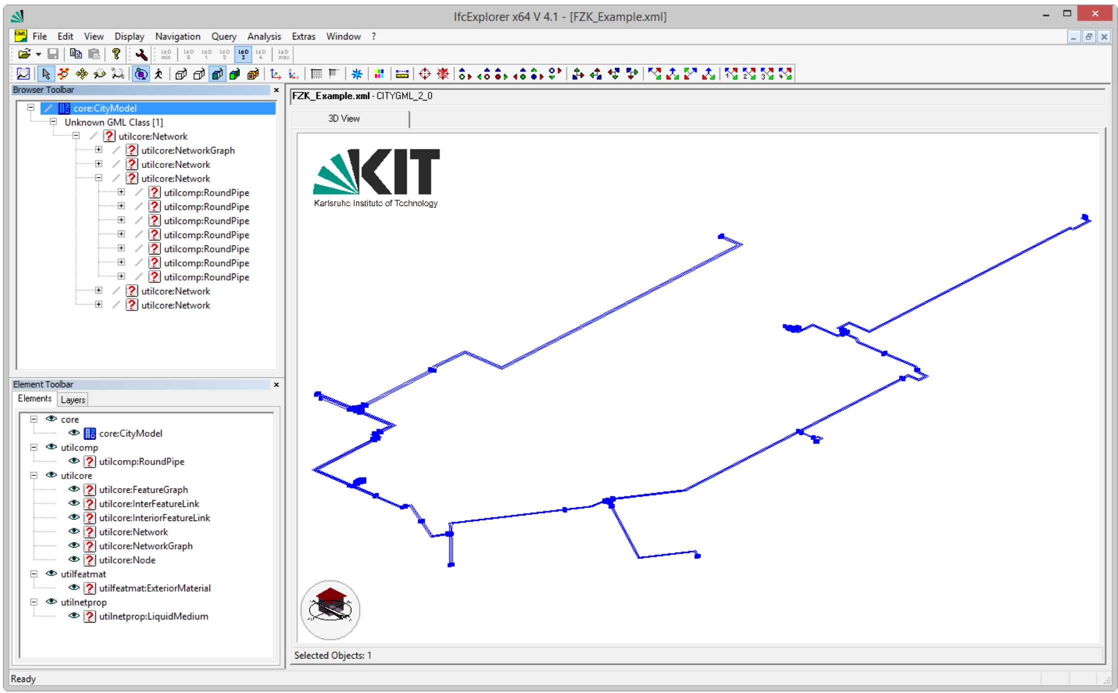

Figure 17: Example of four utility network modelled be using the UtilityNetwork ADE (source KIT, Technical University of Berlin)

The Energy ADE is currently being developed by the Special Interest Group 3D (SIG3D) of German Spatial Data Infrastructure (Geodateninfrastruktur Deutschland GDI-DE) [SIG3D2015]. The ADE will allow to model zones (usage and thermal), thermal boundaries and all necessary material properties. Estimated values for the energy consumption can be attached to the building. As the final XML schema is not yet available, no test models can be presented.

Relevance for STREAMER

CityGML is the only international standardized 3D city model. Even if CityGML is a general-purpose model and not supporting domain specific information, CityGML plays a significant role in STREAMER for modelling neighbourhoods, districts or complete cities. With the Application Domain Extension (ADE) mechanism, CityGML offers a possibility to broaden the scope of the standard and to add domain specific information.

2.3.2 INSPIRE

INSPIRE (Infrastructure for Spatial Information in the European Community) is a directive of the European Parliament and of the Council, which entered into force on 15 May 2007. Its central aim is to create a European Union (EU) spatial data infrastructure. After the directive is fully implemented in 2019, it will be possible to share spatial information all over Europe. For this, the member states have to provide Internet servers supporting metadata information on the affected data sets and enabling data access via viewing and download services.

The INSPIRE directive identifies a number of technical themes, which are explicitly mentioned in three technical annexes. For each of these themes, a specialized, GML-based data exchange format has been defined, which in future will be the European standard for the corresponding technical area. On member state level, all data which must be collected by a public agency due to a national law, which can be associated with one of the INSPIRE themes and are already existing in digital format, are affected by the

directive. This means they have to be integrated into the spatial data infrastructure, and the download services will deliver them in the standardized data format.
The INSPIRE technical themes (see chapter 6.6) are mainly concerned with environmentally relevant data. However, a number of themes are also relevant for the application area of STREAMER.

- **INSPIRE Data Specification on Buildings (D2.8.III.2_v3.0).** The data model is specified with 4 variants: Basic and extended profile with 2D or 3D geometrical representation, respectively. The 3D extended profile, which is not mandatory for the member states, is similar to the CityGML Building module, but has a number of additional, energy relevant attributes (material information for walls and roofs, information about energy performance, heating source and heating system).
- **INSPIRE Data Specification on Human Health and Safety (D2.8.III.5_v3.0).** Information concerning available health services and statistical information concerning health will be provided in this data format.
- **INSPIRE Data Specification on Utility and Government Services (D2.8.III.6_v3.0).** Parts of this specification are two profiles for the modelling of utility networks, including electricity networks and thermal networks.
- **INSPIRE Data Specification on Energy Resources (D2.8.III.20_v3.0).** Information on the potential of renewable energy (solar energy, wind energy, geothermal energy) on a hospital site will be provided in this data format.

Relevance for STREAMER

Providing spatial information with the focus on environmental aspects on European level could be valuable for the STREAMER. However, it is expected that within the STREAMER runtime no significant INSPIRE models for the four demonstration projects will be available. Therefore, it will be important to monitor the progress in the INSPIRE initiative, but the INSPIRE data model will not be considered in the STREAMER project.

2.3.3 OpenStreetMap

OpenStreetMap (OSM) is a world-wide, collaborative project to create a free, editable digital map [OSM2015]. The project started in 2004 and was mainly motivated by restrictions on availability and usage of official map information. OSM data are collected by a large number of local contributors. Normally, map features are registered geometrically, uploaded to the project sever, classified semantically and enriched with thematic attributes, which always have the form of key-value pairs. An ontology exists for the semantic classification and attribution of OSM features, but its usage is not mandatory for contributors.
The main thematic areas of OSM are:

- Traffic networks (streets, cycle ways, railways) and corresponding infrastructure facilities;
- Information about public transportation;
- Electricity network and facilities;
- Buildings;
- Leisure and sports facilities;
- Health and security facilities;
- Natural geo objects like lakes, rivers or rocks;
- Land use data;
- Administrative boundaries.

For these thematic areas the OSM map partly has a good quality and contains more attributive information than “official” geospatial data. However, due to the lack of mandatory recording rules and centralized quality control procedures, the high quality cannot be guaranteed everywhere.
Applications can use OSM data in two different ways: As geo-referenced raster images, or as geographic vector data in a simple XML-format. The access to the OSM servers is delivered by specific Web Services, which are not conformant to OGC Web Services standards (see 2.4).
For planning projects like STREAMER, OSM data may provide relevant information for assessing position and orientation of a new building. The OSM dataset of the Hôpital de la Pitié Salpêtrière in Paris (see Figure 18) contains, among others, information on streets and parking places on the hospital site, metro- and railway stations and green areas, which are needed to assess the quality of environment & operational efficiency (STREAMER D3.1 2014)

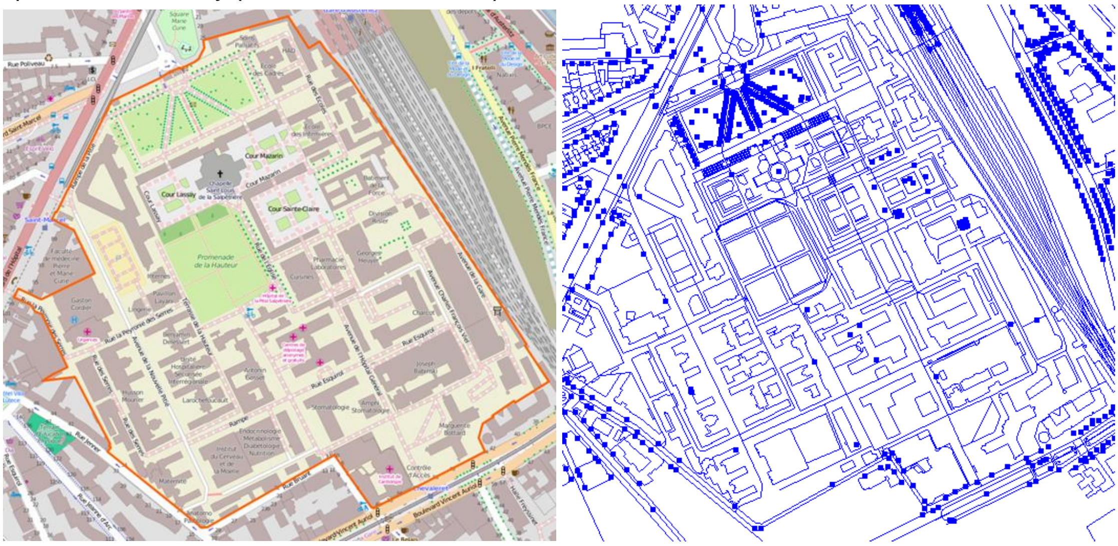

Figure 18: Example of an OpenStreepMap map of Paris (left: map, right: features)

Relevance for STREAMER

Even if OSM is not a standard and the completeness and quality of OSM data depend on public engagement (see chapter 6.7), it is a data source which provides geospatial information about hospital districts and which is easily accessible. If there are no spatial data (e.g. roads or power lines) for the STREAMER demonstration sites available, OSM is an appropriate and suitable alternative.

2.3.4 Keyhole Markup Language (KML)

The Keyhole Markup Language (KML) is a XML-based data format for visualization and annotation of 3D geospatial information. Originally developed by Google for the GoogleEarth application, KML since version 2.2 is an official OGC standard [KML2008]. KML documents may contain geographic vector data (points, lines, linear rings and polygons) and raster data, and can refer to COLLADA models to support high-quality visualization and texturing. Geographic vector data always use geodetic (latitude, longitude, height above sea-level) coordinates and the WGS84 EGM96 geoid.
Unlike CityGML or the different INSPIRE data models, KML is no semantic data model. A KML geometry object (Placemark) has no specified semantic meaning and, except of the textual attributes “name” and “description”, no non-geometric properties. Thus, the usage of KML in the STREAMER project is limited to support visualization. For this, BIM or GIS data need to be transformed into KML/Collada [Collada2015], which is easily possible due to the simplicity of the KML format. Afterwards, the generated

KML representation of the BIM/GIS data set can be visualized with virtual globes like Google Earth [GoogleEarth2015], Marble [Marble2015] or NASA World Wind [WorldWind2015].

Relevance for STREAMER

As a standardized format for visualization spatial content in virtual globes, especially in Google Earth, KML can be relevant for the communication with people who are not directly involved in the construction process. Within STREAMER, KML can be the format to share spatial information (2D, 3D and corresponding annotations) with the public, in order to establish participation.

2.3.5 ESRI Shapefile

The Shapefile format developed by the ESRI company, is a very simple and popular data exchange format for 2D and 3D geospatial data [Shapefile1998]. Though it is not supported by an international standardization organisation, it became a de-facto standard, which is supported by every BIM or GIS tool. Physically, a Shapefile is stored in 3 – 9 different files, which all have the same name, but different extensions. Besides the mandatory files for geometry (*.shp), attributive data (*.dbf) and the linkage of geometry and attributes (*.shx), optionally additional information may be provided. Among these are the projection parameters of the used coordinate reference systems (*.prj), information on the used character set (*.cpg), and Shapefile metadata in XML-format (*.shp.xml).

The main benefit of the ESRI Shapefile is its very simple but powerful structure consisting of a single table. Each row of this table represents one geographic feature, which has exactly one geometric attribute and an arbitrary number of non-geometric attributes. The columns of the table have fixed, geometrical or non-geometrical, data types. In consequence, all features of one Shapefile have the same structure and especially the same geometry type. The Shapefile format supports the following geometry types:

- Point – One single point.
- MultiPoint – An arbitrary number of points.
- Polyline – One or more polyline parts, where each part consists of a connected sequence of two or more points. Different parts must not be connected and may or may not overlap or touch.
- Polygon – One or more rings, where each ring is a connected sequence of four or more points that form a closed, non-intersecting loop. An outer ring of a polygon is oriented in clockwise order; rings defining holes in polygons are in counter clockwise direction.
- MultiPatch – One or more surface patches, where each patch describes a surface in form of a triangle strip, triangle fan or polygon.

Non-geometrical Shapefile attributes may only have the data type integer, real, text or date.

Like KML, the Shapefile format does not specify a certain semantic meaning of a feature or attribute, this has to be specially defined for each use case. However, due to the object oriented structure and the variety of supported geometry types, it is principally possible to map complex data formats on (eventually multiple) Shapefiles. Thus, this data format principally could be used as exchange format between applications, which do not support a common, high-level BIM or GIS interface. This situation is very likely to occur in the STREAMER project, where a large number of different software tools are involved in the design process and need to exchange complex building data.

Relevance for STREAMER

As de-facto standard in the GIS domain, STREAMER has to consider the Shapefile format when using geospatial data from public authorities. Especially, municipalities applying ESRI [ESRI2015] products will provide data in the Shapefile format.

2.4 Web Service Standards

A Web Service is a software application supporting the direct communication between different IT systems via networks. Web Services realize a client – server based, service-oriented architecture, where a client sends requests to a server, and the server delivers the requested information as response. Every Web Service is uniquely identified by a Uniform Resource Identifier (URI) and has a formal description of the supported requests and responses, frequently based on XML. The client-server communication normally uses the HTTP-protocol.

The OGC has developed and standardized a number of Web Services for accessing, exchanging and processing geospatially related data. Among these are:

- A service for accessing raster-based geospatial data: Web Coverage Service (WCS) (OGC 2012);
- Services for visualizing raster-based geospatial data: Web Map Service (WMS) (OGC 2006) and Web Map Tile Service (WMTS) (OGC 2010);
- A service for accessing vector based geospatial data: Web Feature Service (WFS) (OGC 2010a);
- Services for planning and accessing distributed sensors networks: Sensor Planning Service (SPS) (OGC 2011) and Sensor Observation Service (SOS) (OGC 2012a);
- A service for processing geospatial data: Web Processing Service (WPS) (OGC 2007).

The two most relevant OGC Web Service standards in the STREAMER context are described in more detail subsequently.

In the area of BIM, there is also an initiative to standardize web services in order to interact between different BIM services. In chapter 2.4.3, the BIMsie project is described in more detail.

2.4.1 OGC Web Map Service

The Web Map Service (WMS) provides a standardized interface for requesting geo-referenced map images from geospatial databases. A WMS request defines one or more layers to be delivered in a certain area of interest. The corresponding response consists of one or more geo-referenced map images, delivered in different map formats like PNG, JPG, etc. In the request, it can also be specified that selected returned images should be transparent. Thus, different map layers may be combined.

WMS data only support the visualization of geospatial information. Its practical usage in the STREAMER context therefore is limited. It is imaginable to overlay an early design model of a new hospital building with WMS delivered images of the building's neighbourhood, for visually assessing the imbedding of the new building into the existing environment (see Figure 19). However, for a quantitative assessment of the neighbourhood impact, access to geographic vector data is needed, which can only be delivered by a Web Feature Service (see 2.4.2).

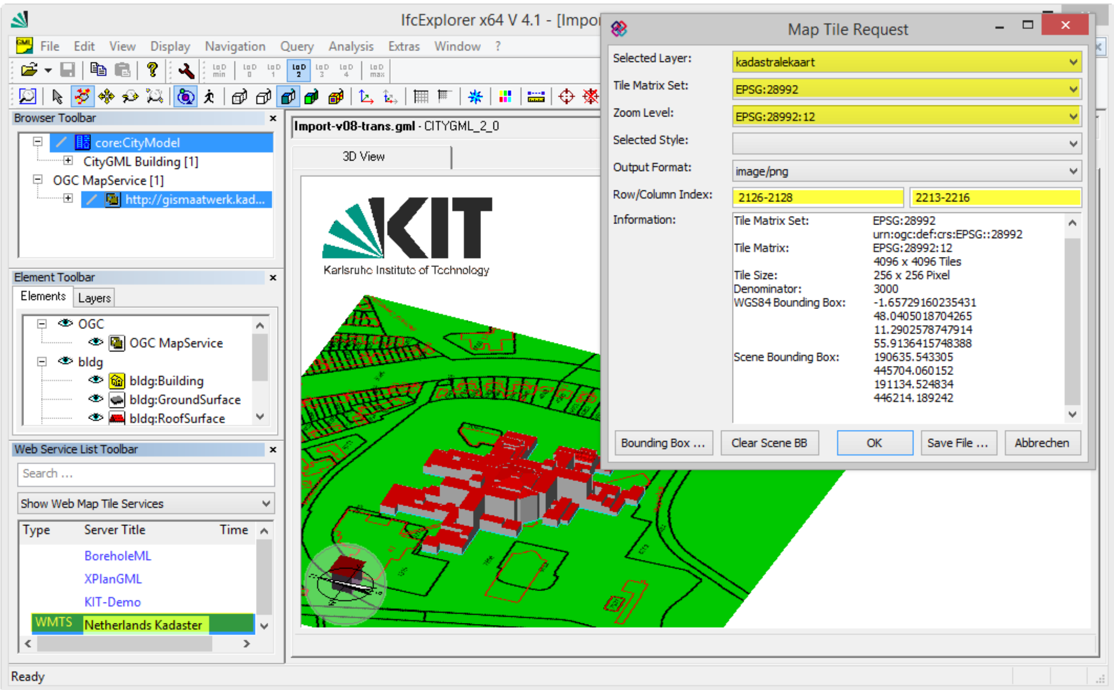

Figure 19: Example of a Web Map Service: The building is loaded from local disk, while the map (12 tiles) is added via WMS from a Dutch map server for cadastral data (server, layer, coordinate reference system and zoom level are highlighted)

Relevance for STREAMER

Usually a WMS is delivering a map in an image format (PNG, JPG). For case studies or during the early design phase, maps can help to find possible locations and to identify further restrictions (e.g. protected areas) or additional changes (e.g. geothermal potentials). Depending on the required data, different authorities are responsible to provide the maps. For STREAMER, Web Map Services are imported, because they allow a quick, selective access to various maps from different sources.

2.4.2 OGC Web Feature Service

The Web Feature Service (WFS) standard specifies the behaviour of a Web Service for accessing geographic vector data, mostly denoted as geographic features. In most cases, WFS only supports discovery and query operations. With discovery operations, the capabilities of the service with respect to, e.g., delivered feature types, supported coordinate reference systems or querying functionality may be requested. Furthermore, the GML applications schema of the feature types may be retrieved. Query operations allow clients to retrieve features from the data store based upon user defined filter conditions on spatial or attributive feature properties (see Figure 20).

In addition to discovery and query operations, a Transactional WFS (WFS-T) also supports locking and transaction operations for changing, creating, replacing or deleting features in the database.

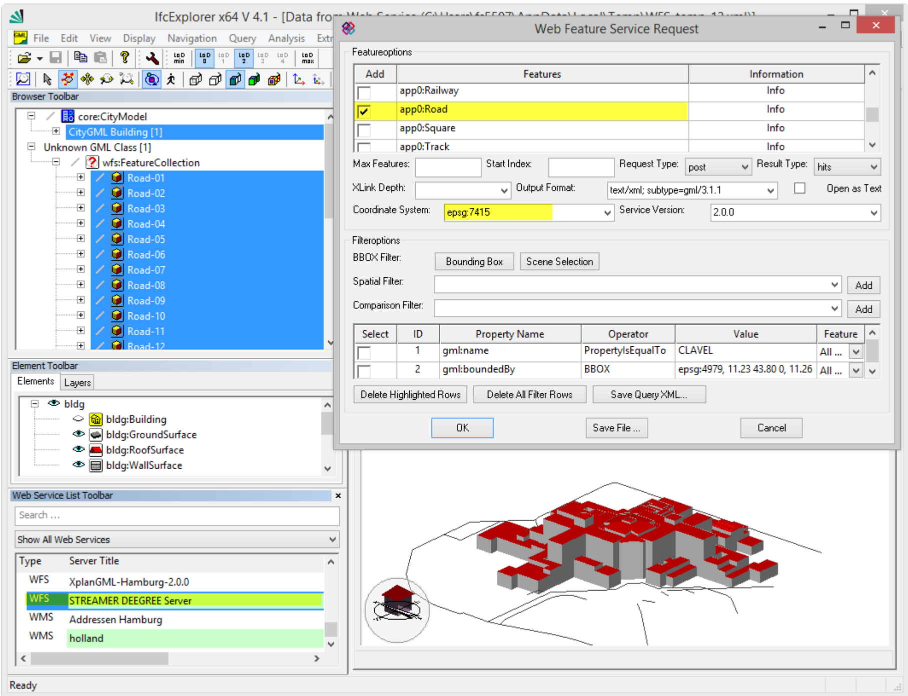

Figure 20: Example of a Web Feature Service: The building is loaded from local disk, while the roads are added via WFS from the STREAMER DEGREE Server (server, coordinate reference system and selected features (Road) are highlighted)

Relevance for STREAMER

If vector data (2D and 3D) are required, the Web Feature Service is a standardized way to access geospatial databases. Similar to the WMS, the WFS allows a quick and selective access to distributed databases. As more and more 3D city models (CityGML) are available and mainly stored in databases, the WFS is important for STREAMER to access the hospital district itself and the surrounding of the district.

2.4.3 buildingSMART BIMsie (BIM Server Information Exchange)

Different online BIM services from Autodesk, Bentley, Tekla, Graphisoft, Nemetschek, Onuma and others support different APIs. Connecting BIM applications requires n*(n-1)/2 custom interfaces. Data can also be exchanged using standard like IFC or COBie but this requires human intervention. Implementing BIM in the cloud requires automated (machine-to-machine) interaction between different online BIM services. A standardized web services API for online BIM services would enable machine-to-machine exchange of BIM data and enable innovation in the industry. BIMsie is intended for this, being the open web services API for online BIM services [BIMsie2015].

BIMsie relies on existing standards as much as possible. Currently BIMsie supports JSON and SOAP, but is designed to be independent of protocol so that other protocols could be added if required. For example, BIMsie also uses existing web standards for authentication and encryption.

BIMsie is comprised of modules such as 'ServiceInterface' with 36 services, 'NotificationInterface' with 12, 'RemoteServiceInterface' with 4, and 'Authinterface' with 7. Software vendors can choose which modules they support in their application. Not all modules are required in every BIM application. The API calls/services are documented on the BuildingSMART page of github. The documentation includes descriptions and example code. There is also an online BIMsie compliant service for testing.

The first version of BIMsie 1.0 was released in July 2013. As of January 2014 BIMsie is in the process of being updated to V1.1. At this moment, several software vendors are implementing BIMsie modules in their software interface. The BIMserver, a commonly used platform for sharing BIM data, supports BIMsie.

Relevance for STREAMER

As BIM models across all disciplines (e.g. architecture, building services, structural) can get huge and unhandy, it is more suitable to work with partial models. BIMservers are designed to merge BIM models from different sources, to create partial models and to manage the data in order to have a consistent database. Similar to the OGC web services, buildingSMART BIMsie offers a standardized interface to BIM servers. It is strongly recommended, to test BIMsie and if applicable to use it in the STREAMER project.

3. Advanced Mapping

A central challenge of STREAMER is the large number of different software applications or tools being used in the different stages of the design process. For the complete process to proceed smoothly and without loss of information, a seamless interfacing of the different system components is needed. This is complicated by a number of technical issues:

- The software tools involved in the STREAMER process come from different technical areas (e.g. BIM, GIS, energy simulation, optimization, decision support. …) and therefore support different data models, data quality and data exchange formats.
- In most cases, software tools already existing on the market are used, where the possibility to adapt or extend the interface functionality is very limited.
- In some cases, the same real-world object is represented simultaneously in different formats (e.g. BIM and GIS data) and the objects have to be merged for evaluation purposes.
- In some cases spatially related information using different coordinate systems (e.g. local coordinates and global geographic coordinates) have to be combined.
- Depending on the data model and the application area, different geometrical representations are involved. In general, these representations (volume, surface, line, point) cannot be converted bidirectionally.
- As the data models are based on different modelling languages, different software tools are necessary to read, check, process and write the models.

This chapter illustrates a number of techniques for solving the above mentioned issues by STREAMER relevant examples.

3.1 Enriching

In general, data enriching can be defined as enhancing or increasing the information content of a data set with either manually produced or externally stored data. Data enriching normally is supported by a specialized enriching application which reads the data set, supports the manually controlled or automatically performed enriching process, and finally exports the enriched data in the same data format.

Two typical examples for data enriching in the STREAMER context are described subsequently: The enriching of IFC data for its usage in the energy simulation system TRNSYS, and the enriching of IFC represented material data by ecological data from life-cycle data bases.

3.1.1 IFC data enriching for TRNSYS

In order to build an input data file for TRNSYS, we need additional data regarding the building geometrical description. Some of these data are already well described in the IFC format (e.g. thermal properties of a wall material layer, or U-value for wall). It is globally the case for the description of the whole building envelope. However, it is not necessarily the same for other technical data such as equipment parameters. Indeed, taking the example of the solar panel, we can observe that there is no property for this equipment in IFC2x3, and that only weight and surface are described in IFC4.

Of course, the mathematical model from TRNSYS, which simulates a solar panel, needs a lot of other parameters. Furthermore, the principle of wiring diagram in the TRNSYS simulation studio interface (as shown in Figure 21) requires knowledge of all input/output of a given equipment model (represented by a “box”) in order to connect it to the rest of the system [Robert2015].

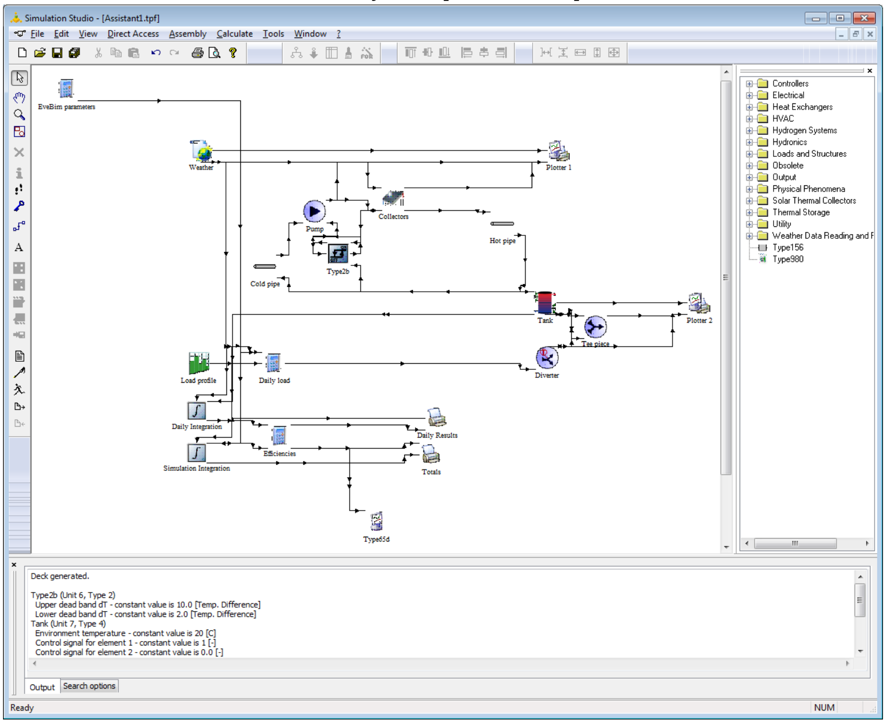

Figure 21: Wiring diagram of the Trnsys simulation studio

As it does not seem realistic to build such a wiring diagram directly from IFC file, the use of a template (e.g. Multizone Building or 3D Building) is necessary (corresponding to the wiring diagram). In this kind of diagram, each box corresponds to a mathematical model that describes the equipment’s behaviour. The “wiring” of several boxes thus constitutes a complete system. Let us indicate that some of them have no existence in the “construction world” but are rather "numerical" objects (addition of signals for example). These objects are then not recoverable from an IFC file and therefore justify creating template file as a *.dck file for TRNSYS in advance.

Another question concerns the validity of data about thermal properties of the materials or the thermal performance of walls. Beyond the geometry of the envelope (orientation, solar mask …), these properties have a huge influence on the results of the energy estimation.

Today, there are multiple databases that characterize the material properties of a thermal viewpoint (experimental test, base end of the literature …). Therefore, even if the IFC file contains material properties (or thermal performance for walls), chances are that the engineer will want to provide these properties’ values himself, not least because that he wishes to consider several variants with different materials to compare their performance. More generally, engineer needs to control the BIM model and, if it is necessary, to adapt it for simulation purposes (as for example to define his own thermal zones from IFC spaces).

By taking into account these constraints, the establishment of an intermediate tool became necessary (Figure 22). The benefits of a third-party tool for the thermal engineer are:

- To associate its own material properties (or wall thermal resistance),
- To build its own thermal zones,

- To keep unchanged associations (between GUID from IFC and thermal properties) in case of architect's modifications,
- To save these additional data into a BIM model (alone IFC file or with external documents attached).

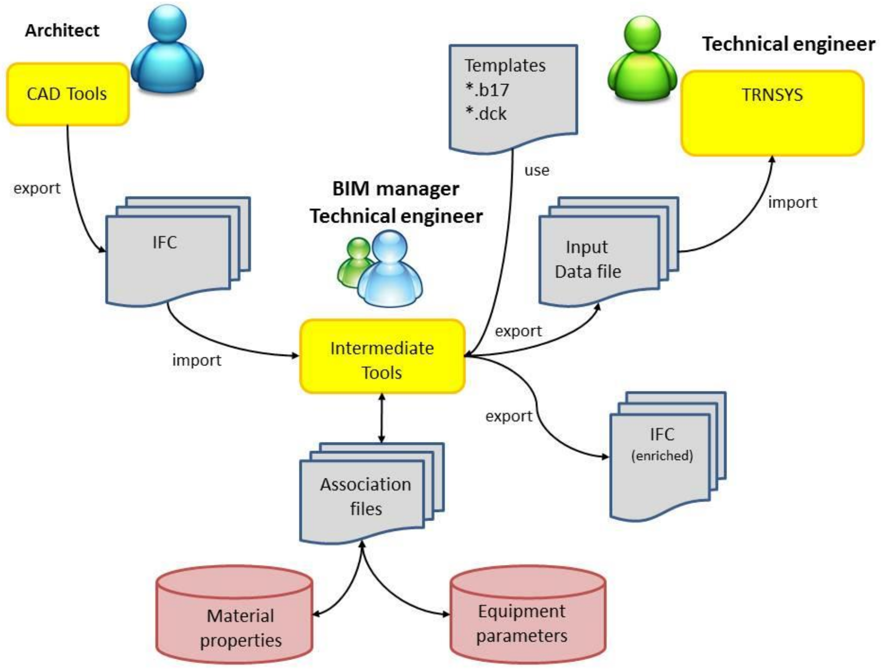

Figure 22: Workflow for enriching IFC models for energy simulation with Trnsys

Finally, from the geometrical point of view, IFC object geometry is mostly defined as 3D solid. IFC spaces are then separated from each other by walls or slab thickness. In a 3D surface model such as TRNSYS needs, walls and slab do not have any thickness and the thermal zones are in contact with each other.

If the engineer wishes to verify the input 3D model for TRNSYS by using Sketchup, it is necessary to transform this 3D solid geometry of the space into a 3D surface as presented in the picture below (Figure 23).

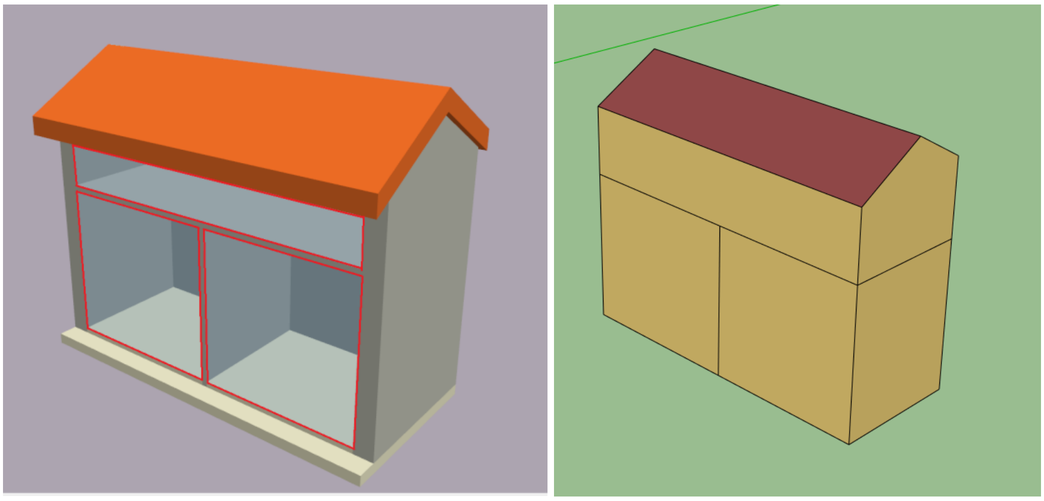

Figure 23: Solid geometry of spaces and building elements (left), surface representation of the relevant building elements (right)

In conclusion, the simulation in TRNSYS with an IFC file consists of first creating an adequate template, regarding the kind of targeted simulation. Then the engineer will then complete data by using the intermediate tool (eveBIM-Trnsys in our case) with building data retrieved from the IFC file and also from external databases (or external files) for material properties and equipment parameters. At the end, he can save the final configuration in an IFC file (with external files attached if necessary).

3.1.2 Enriching IFCOBJECTTYPE with ecological data

As mentioned in chapter 2.2.5, life cycle inventory data are available on national [ÖKO2015] and European level [LCA2014]. Linking this information to IFC objects is described in chapter 3.4. After accessing the LCI data, simulation or analysis can be directly performed or, if required, the data can be attached to IFC, in order to extend the building model.

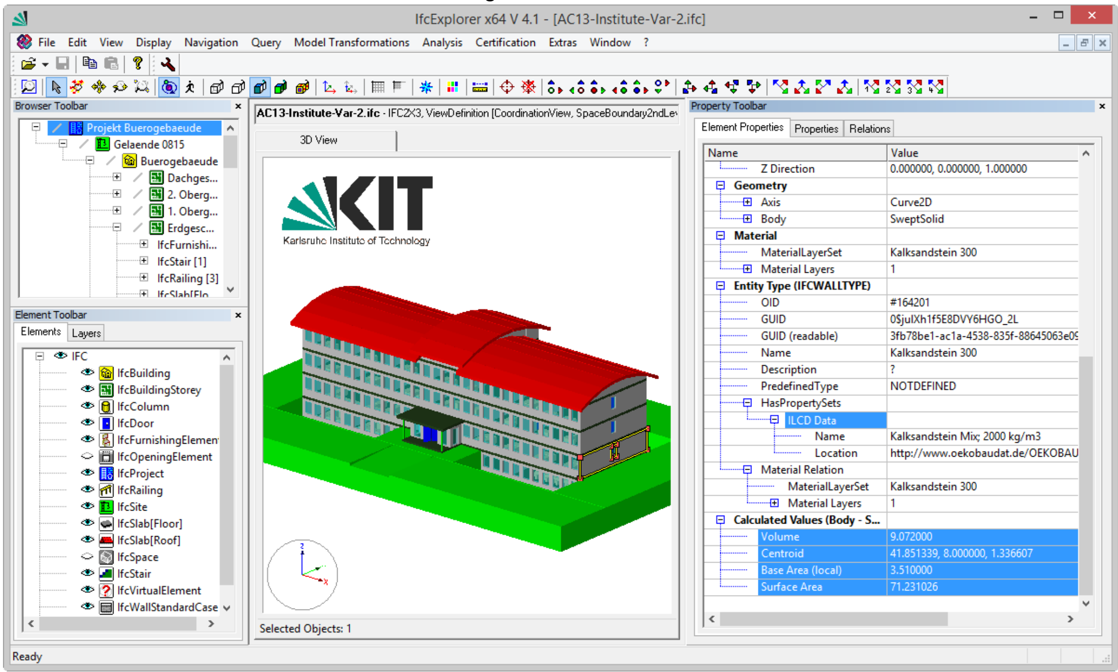

Figure 24: IFC model enriched by prototypical ILCAD data and by calculated base quantities (highlighted in the property window on the right side)

In the first prototype implementation in the IFCExplorer environment, the LCI data will be attached to a building element type (e.g. IFCWALLTYPE or IFCBEAMTYPE). Currently only very basic information is stored in a new property set (ILCD data), which is assigned to a building element type. This means all building elements of the same type will have the LCI information. Together with calculated base quantities (volume, base area and surface area), the individual building elements can be analysed (see Figure 24 highlighted properties). With IFC4 a limited number of environmental impact parameters can be stored in standard IFC property set (see chapter 6.5).

3.2 Geometric/semantic transformation

In contrast to data enriching, a geometric/semantic transformation converts a data set containing semantically enriched geometry data from an initial data format into a new target data format. During a transformation process the information content of the transformed data set may decrease (in case not all information of the initial format can or shall be represented in the target format), it may remain constant, or in some cases it may even increase (see 3.2.1). Potentially, there are many situations enforcing a geometric/semantic transformation. The most frequent use-case is that the application foreseen to process the data set not directly supports the initial data format. In the following, a number of techniques and algorithms for transforming data between BIM and GIS data formats are reported: IFC to CityGML (chapter 3.2.2), CityGML to gbXML (chapter 3.2.3), and VDI3805 to IFC (chapter 3.2.5).

3.2.1 Purely geometrical data to IFC

In many practical cases, CAD data containing no or insufficient semantic information are available as initial model for a design process. In the STREAMER project, this occurred as the geometry model of the Careggy hospital site was adopted. The available data set (in AutoCAD DXF format) contained the volumetric geometry of all hospital buildings on the site. For each building, separate solid objects were generated for different building storeys, but the data set did not contain any (explicit) information, which of these volumes belongs to the same real-world building.

For efficiently using these data in the STREAMER context, they were transformed into IFC in the following way:

- Every DXF solid was transformed into an IFCBUILDINGSTOREY object with solid geometry,
- All IFCBUILDINGSTOREY objects belonging to the same real-world building were aggregated by an IFCBUILDING object without explicit geometrical representation.

No existing CAD system is able to perform this transformation. Therefore, specific transformation software had to be developed, which can be used in the following workflow (see Figure 25):

- The DXF model is imported into the CAD tool AutoCAD Architecture (ACA).
- By using the standard IFC exporter of ACA, an intermediate IFC model is generated. In this intermediate model, every DXF solid is represented as IFCBUILDINGELEMENTPROXY object with solid geometry.
- A specially developed transformation software (a new module of the IFCExplorer) imports, analyses and enhances the IFC model:
  - IFCBUILDINGELEMENTPROXY objects are converted into IFCBUILDINGSTOREY objects.
  - By a geometric analysis based on the footprints of the storey volumes, it is detected which IFCBUILDINGSTOREY objects belong to the same building. If two footprints overlap (directly or indirectly, see Figure 26), they are classified to belong to the same building. Storeys whose footprints are disjoint or only touch at the boundary are regarded to belong to different buildings.
  - For all aggregations of IFCBUILDINGSTOREY objects detected in the previous step, IFCBUILDING objects without geometrical representation are generated.
- The enhanced IFC Model (which is not conformant with the IFC CoordinationView 2.0) is exported (see Figure 27).

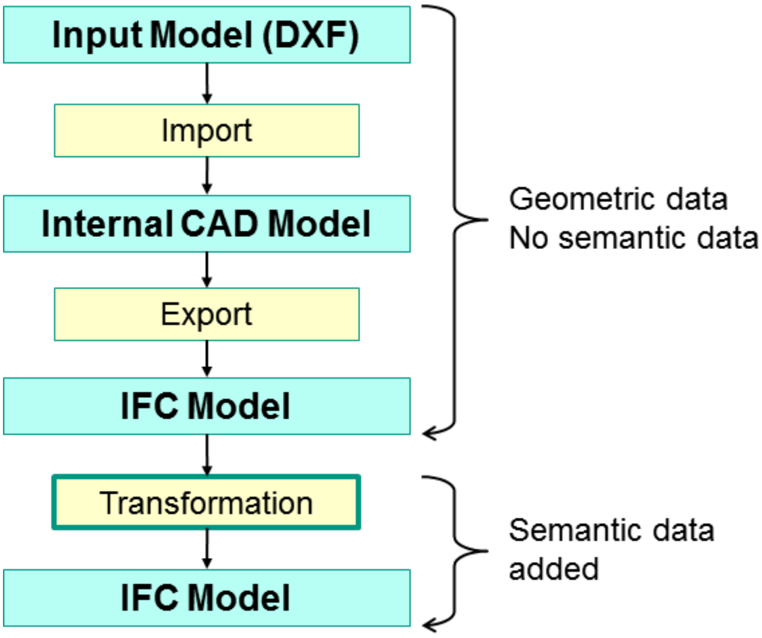

Figure 25: Full transformation from DXF to IFC with semantic data

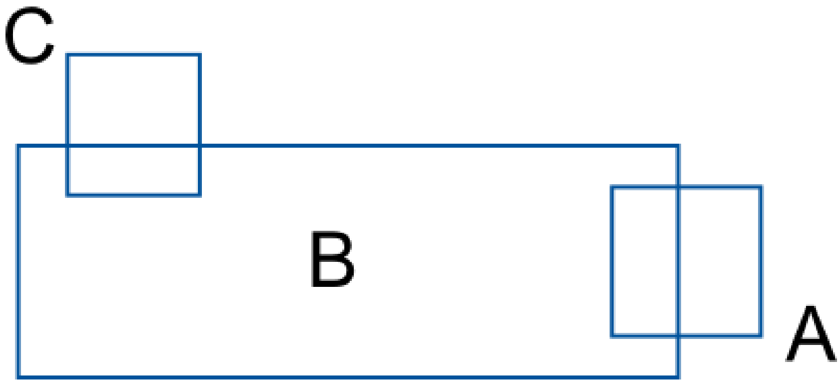

Figure 26: Example for overlapping geometric volumes

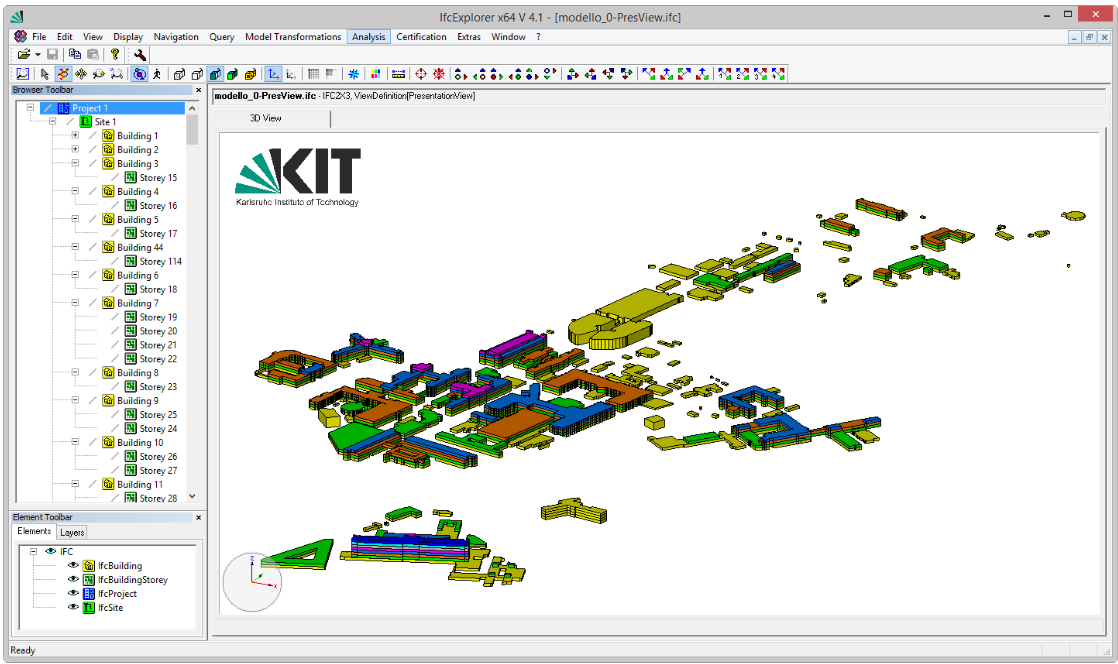

Figure 27: The converted IFC model of Careggy hospital (139 IFCBUILDING)

3.2.2 IFC to CityGML

Today, Building Information Modeling (BIM, openBIM, IFC) is mainly related to detailed architectural models. Such models typically contain a lot of detailed geometrical and semantical information. Actually, these models are intended to cover the complete life cycle of the building, including the construction process itself. For applications such as noise simulation, emergency management or energy simulation on larger scales, which need to process multiple buildings, this representation might be too detailed.
The building module of CityGML allows modelling a building in five Levels of Detail (LoD). Depending on the scale (neighbourhood, city, region, state) and the application, buildings in different LoD might be suitable. Beside other generation methods like aerial laser scanning, one method for generating low LoD models can be the generalization of detailed BIM (IFC) models [Nagel2007] [Geiger2014] [Donkers2013].
The generalization process developed for STREAMER is focusing on the outer shell of the building. Figure 28 shows an example of an IFC building which is generalized to a block model (LoD 1), a general outer shell without openings (LoD 2) and an outer shell with doors and windows (LoD 3).

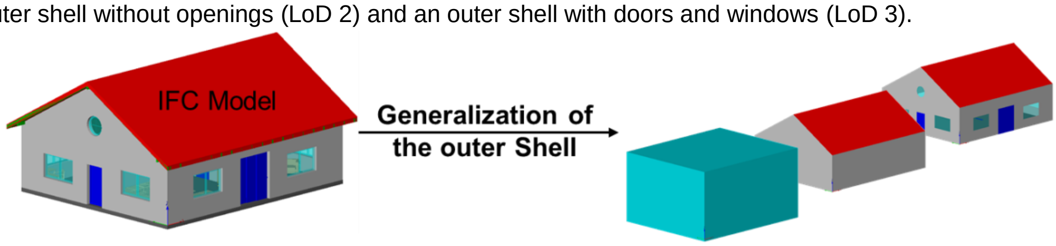

Figure 28: Generalization of the outer shell of an IFC building

Figure 29 schematically depicts the generalization processes. After reading the IFC model, in a first transformation step a simplified extrusion model is created. This model results from the projection of each relevant building element onto the horizontal floor plane of the corresponding storey. For each storey the projections are analysed, merged, adjusted, and extruded to the corresponding elevations.

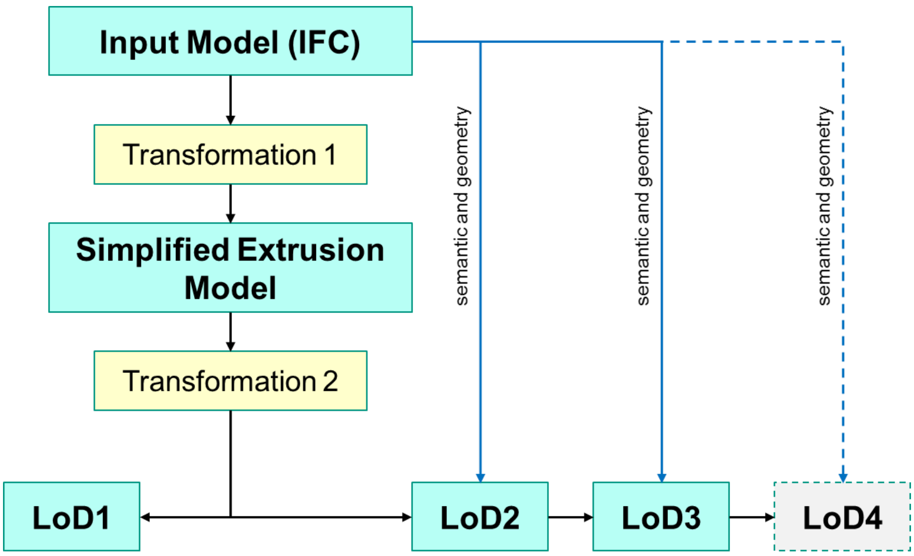

Figure 29: Overview of the process to generalize IFC buildings

In a second transformation step, three different representations of the building's outer shell can be generated. Merging the footprints of all storeys and extruding the complete footprint using the complete height of the building will result in the block model. Only considering the IFC building elements wall, slab and roof, will produce a generalized outer shell without openings. Considering in addition IFC doors and windows, will produce a semantically enriched outer shell [Geiger2014].

For persistent storage, the different generalizations can be exported in CityGML or IFC format. The generation of gbXML models is also possible, but has not yet been realized.

Figure 30 shows three simple examples of generalizing IFC buildings. The first example focuses on balconies. As balconies do not belong to the outer shell, which defines the volume of building, they are separated. The second example contains a very detailed curtain wall. This curtain wall is replaced by a simplified wall surface. The last example includes a loggia. The generalization process preserves this loggia and creates floor and ceiling surfaces to border the loggia vertically.

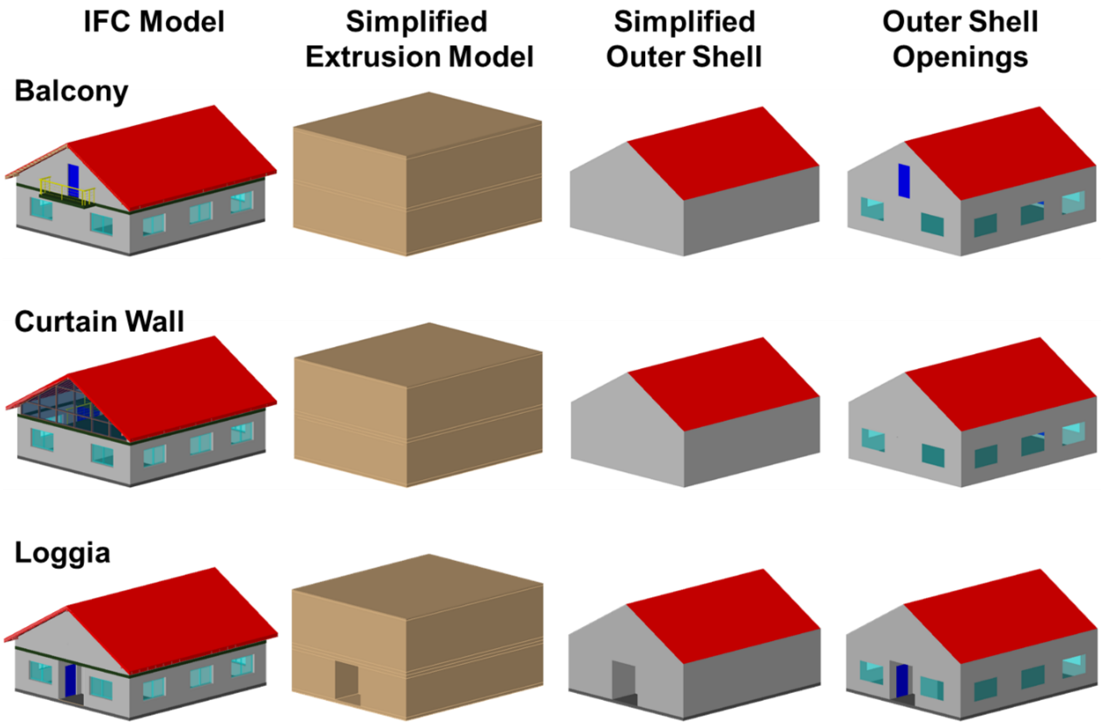

Figure 30: Examples for generalizing the outer shell of an IFC building [Geiger2014]

3.2.3 CityGML (Building) to IFC

Nowadays, more and more cities and municipalities have 3D city models for varies purposes like visualization, marketing and urban planning. The detailing of such city models ranges from block models (building LoD 1) to generalized outer building shell models (LoD2) to detailed LoD 3 model for selected landmarks. The 3D city models are usually stored in databases and available as CityGML models via Web Feature Service. For starting a new project, it might be helpful to have the existing stock as reference in the CAAD application. As most of the CAAD are supporting IFC, but not CityGML a transformation CityGML to IFC can solve the problem.

The IFCExplorer is able to convert CityGML building models (LoD1 and LoD2) into IFC. Currently there is only a semantic transformation and the geometry is left unchanged. This leads to exported IFC model, which is compliant to the IFC schema, but not to the restrictions of the IFC2x3 Coordination View 2.0.

Figure 31 depicts the CityGML model of the Rijnstate main building. It is a LoD 2 model with 1 GroundSurface, 140 RoofSurface, 209 WallSurface and a solid geometry for the complete building. The model is local at the correct position using the “EPSG:28992 - Amersfoort / RD New” coordinate reference system. Currently this CRS is ignored while converting the model into IFC, so that the result is in local coordinates.

The resulting IFC model contains 1 Building with the volume geometry of the complete building, 209 IFCWALL entities with surface geometry, 140 IFCSLAB (type roof) with surface geometry and 1 IFCSLAB (type base slab) with surface geometry.

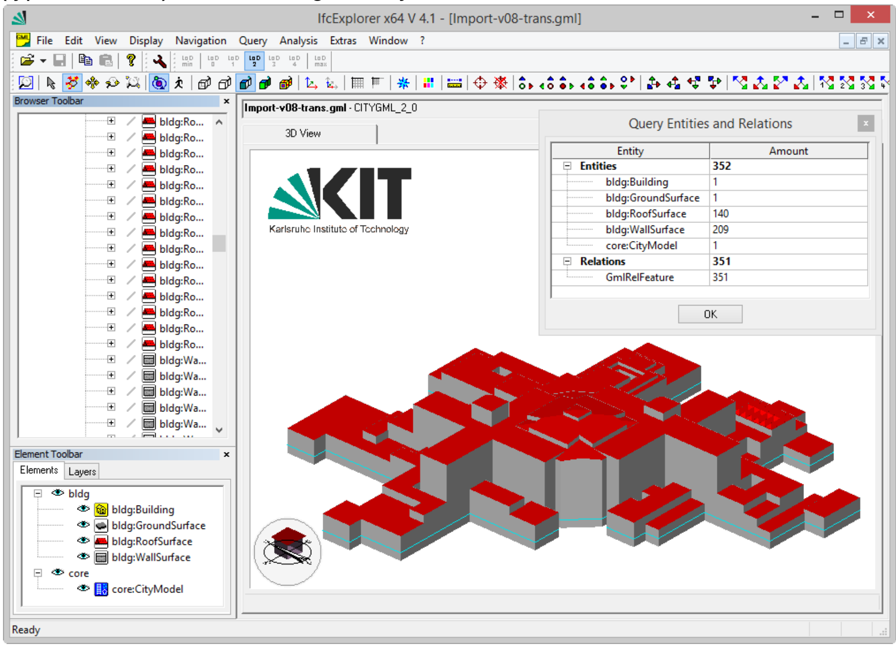

Figure 31: The CityGML model of the main building of the Rijnstate hospital district

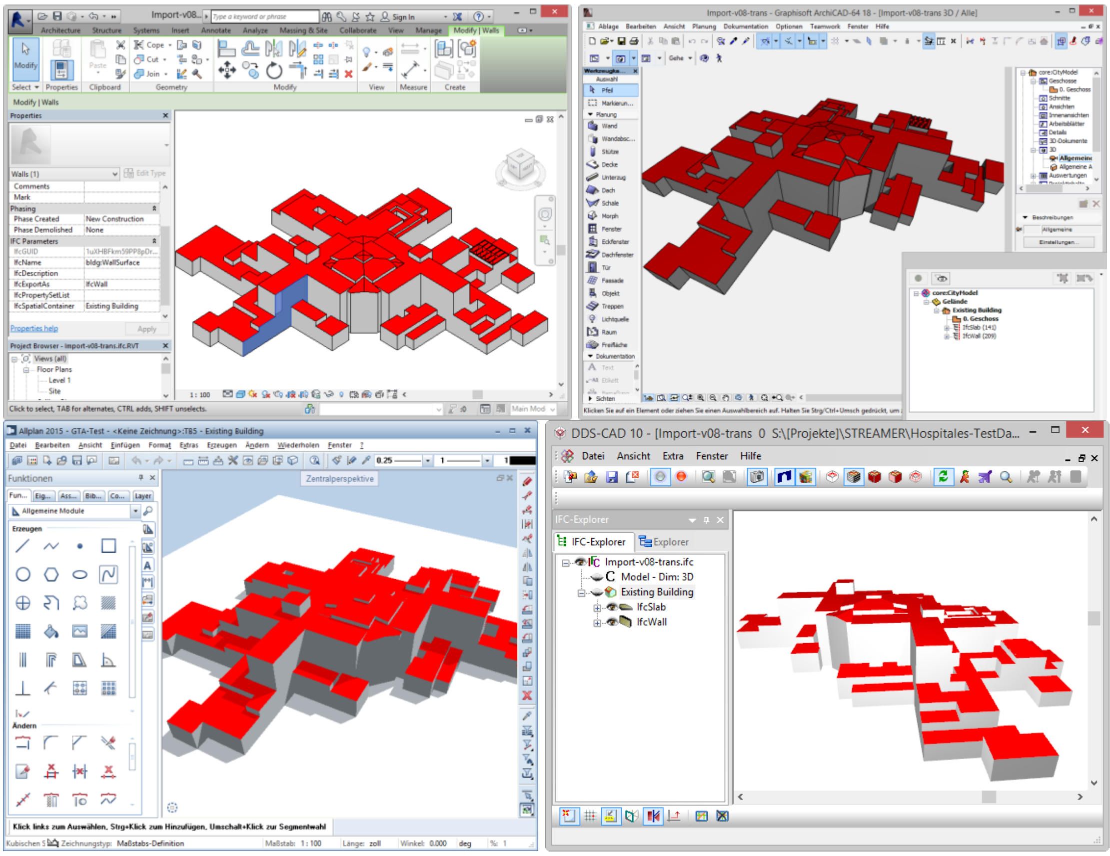

Figure 32: Import of the converted IFC model into REVIT (upper left), ArchiCAD (upper right), Allplan (lower left) and DDS-CAD (lower right)

The use of the converted IFC model is tested by importing the model into a selection of CAAD systems (see Figure 32). REVIT imports both the solid from the building itself and the boundary surfaces. All IFC entities are marked with correct entity type. ArchiCAD imports the boundary surfaces correctly as library object with the correct IFC entity type. Allplan imports the boundary surface correctly as “Makro” or “Mengenkörper” with correct entity type. DDS-CAD 10 loads the complete model including the solid geometry of the building.

In all involved CAAD systems the geometry is imported correctly. The IFC entities are converted into native entities (Library objects, Makros) which usually can only be modified by rudimentary geometric functionalities. Nevertheless, for measurements and case studies the imported models can be valuable.

3.2.4 CityGML to gbXML

Due to advanced data capturing, like airborne laser scanning, building models with generalized roof, wall and ground surfaces can be efficiently generated for regions, cities or districts. These building models usually are delivered as CityGML LoD2 models. For using these models for energy estimation, there are two obstacles:

- None of the commercial software application for energy calculation/estimation has an interface for CityGML,
- the CityGML model lacks relevant features for material properties, and the building structure does not directly match the space oriented structure (thermal zones) of the calculation/estimation software.

One solution can be to extend CityGML by the missing features (see Chapter 2.3.1) and to motivate software vendors to support CityGML.

Another solution can be to convert the CityGML model to gbXML, which is much more supported by engineering analysis tools.

As both, CityGML and gbXML, are based on XML, a simple transformation can be performed by using an Extensible Stylesheet Language Transformation (XSLT). In a first proof of concept of such a transformation, for each CityGML building a gbXML building with a single space is generated. All boundary surfaces of the CityGML building are then assigned to this space. In addition, for each surface (ExteriorWall, Roof and UndergroundSlab) standard material properties are generated.

Figure 33 shows the original CityGML model (left) and the converted gbXML model of Rijnstate hospital. Geometrically both models look the same, but in CityGML the boundary surfaces are assigned to the building while in gbXML the surfaces are assigned to a space.

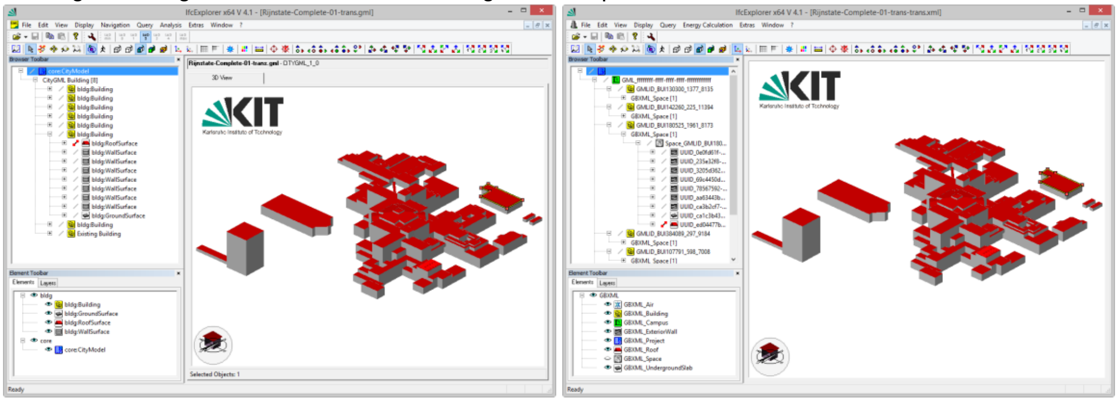

Figure 33: LoD2 CityGML model on the left side and the converted gbXML model on the right side

With this prototypical transformation, it is possible to test models with a number of buildings in commercial analysis tools. For example, the model of Rijnstate was imported into IES Virtual Environment (VE2014). Figure 34 shows the geometry of the model. The model still does not fulfil all requirements of VE2014 to run the simulation. Further tests are needed and the transformation must be improved.

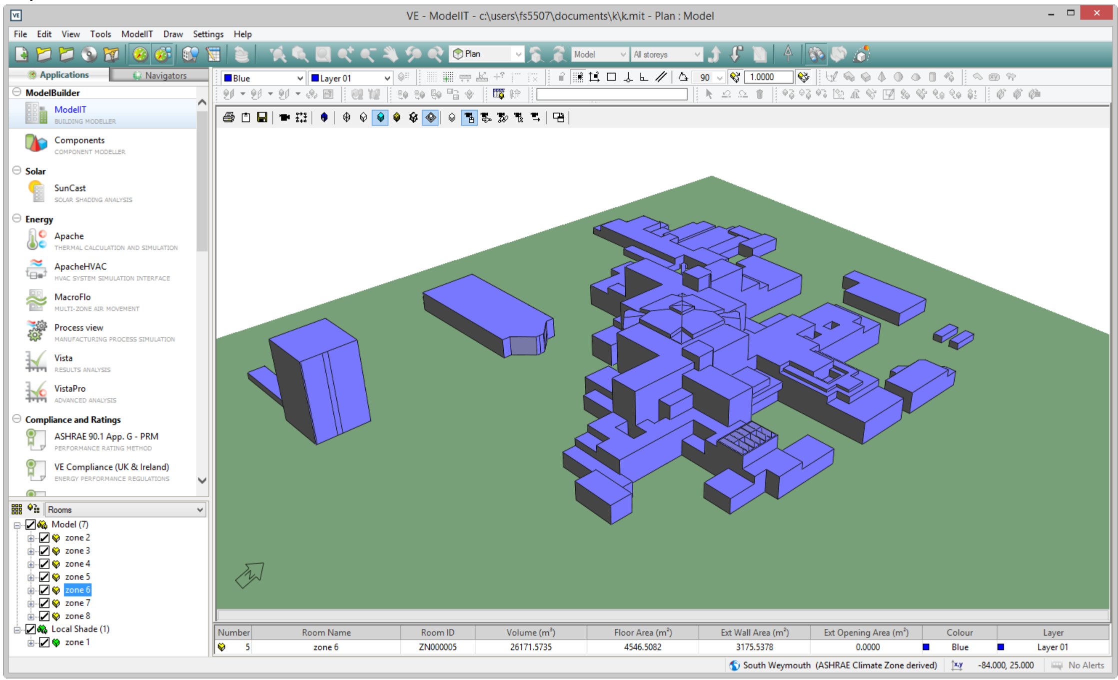

Figure 34: The Rijnstate hospital model imported into IES VE2014

Further improvements of the conversion, like the correct transformation of the reference coordinate system (gbXML supports only longitude, latitude and elevation) and the refinement of the models in multi zone models, cannot be performed in a simple XSL transformation. Such extended transformation are better performed by software, which already can read CityGML, deal with different reference coordinate systems and which already offers geometrical computation.

3.2.5 VDI3805 to IFC

The transformation from VDI3805 to IFC is an example for converting a fully parametric model into non-parametric model. HVAC components usually occur in a number of variants and with a number of corresponding accessories. Before starting the conversion, the user has to select the specific product including all accessories by choosing the desired variant. In order to confirm the selection, the product will be displayed in 3D including all technical details. In Figure 35 a radiator is selected by choosing the dimensions (height, length), selecting the appearance (material colour) and determining the type and geometry of the connector.

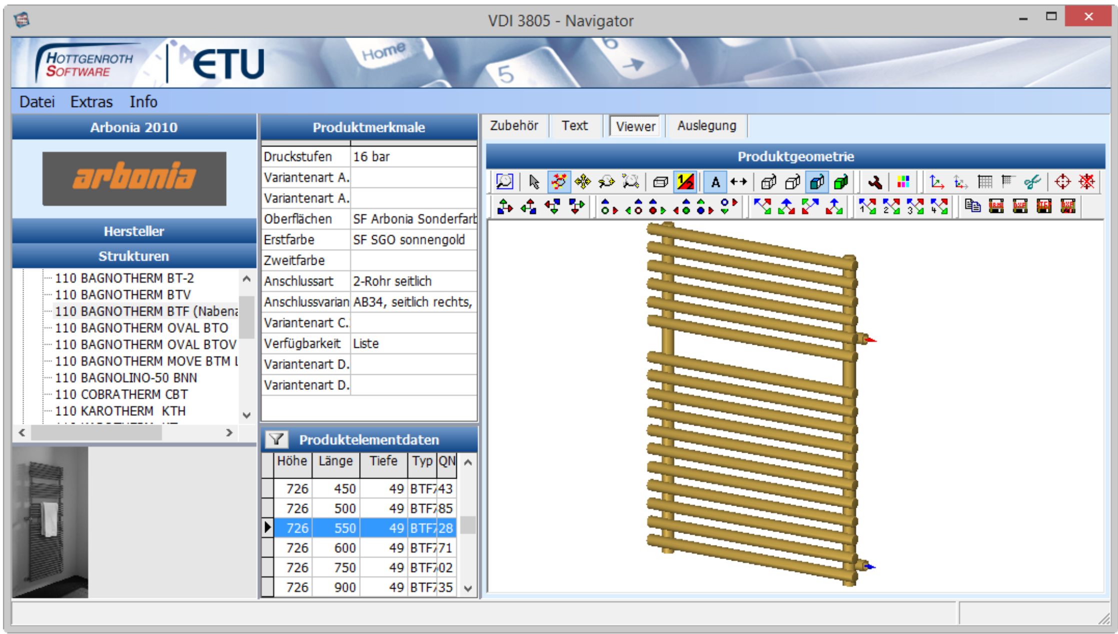

Figure 35: Example of a selected radiator for a bathroom

After selecting the desired product, the model can be exported as IFC, ifcXML and other 3D formats. If not further specified, the product will be exported as IFCDISTRIBUTIONELEMENT. The geometry is converted to a set of surfaces or solids. The colour is preserved as visual styles in the IFC model. All connection information is converted into a set of ports in the IFC model. Figure 36 shows the result of the conversion. Please note that the colours of the connectors do not necessarily correspond (VDI3805 red = heating flow, IFC blue = source). In the current software, there are no IFC properties created, but the complete VDI3805 parametric code is attached as IFC property set.

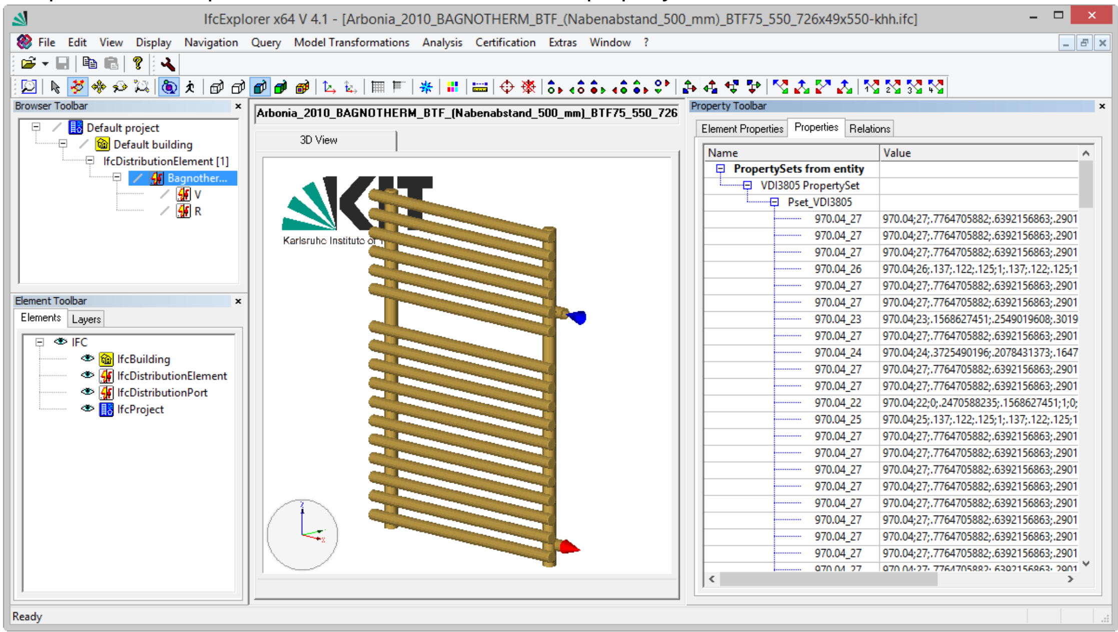

Figure 36: The exported VDI3805 product model imported in the IFCExplorer as IFC model

3.3 Integration

Especially in cross-domain projects like STREAMER (BIM and GIS) it is unlikely that the project can be performed using only a single data model. In the GIS domain (neighbourhood), the Shapefile format is widely used, followed by DXF, GML application schemas (e.g. CityGML) or OpenStreetMap. In the BIM domain, the IFC standard is accepted and widely supported by all major AEC software applications. Nevertheless, if talking about refurbishment projects, other formats like DXF/DWG, PDF and Excel are involved.

In order to get a holistic view of the project and to run simulations and analysis on an integrated model, it is necessary to have all relevant models in one application.

3.3.1 Integration with IFCExplorer

The IFCExplorer [Benner2013] allows integrating the following formats/models into one scene:

- **BIM:** IFC, gbXML
- **GIS:** CityGML, Shapefile, KML, BoreholeML, ALKIS, OpenStreetMap
- **Others:** DXF, Point Clouds, VRML

One of the challenges integrating different data formats within their spatial context is to manage the different Coordinate Reference Systems (CRS). The IFCExplorer is using a software library to convert the different coordinate systems. The first model, which is imported, will determine the coordinate system. For user information, the bounding box will be held in the original CRS, in geographic coordinates (latitude, longitude) and in local Cartesian coordinates. Internally for each model, the original CRS is stored.

For integrating data, all relevant model specific information is stored. The data structure of the IFCExplorer is representing the original elements, entities and features as well as all of their relations to preserve the complete semantic information. This allows detailed analysis across the different data models with access to all attributes or properties.

To fulfil the requirements of a graphical integration of different data models, the internal data structure represents a wide range of geometry types. Starting from surface based geometry, different solid geometry types (e.g. parametric definitions and CSG), 2D and 3D curves and points are supported.

Integrating different data models is also a challenge to the user interface of a software application. If only one model is loading, the user interface reflects the capabilities of that model (e.g. LoD switching of CityGML, different representation contexts in IFC). If more than one model is loaded, the user interface has to be extended by functions, which are specific for the corresponding model. Currently, such a dynamically changing user interface is not realized in the IFCExplorer and the first model, which is loaded, determines the user interface.

As not all data are stored in 3D models (especially in the GIS domain), the integration process must be able to deal with 2D data sets as well. In order to display 2D data in a 3D scene, the following issues have to be considered:

- the z location of the 2D data has to be determined, to get a reasonable 3D visualization (e.g. adaption of the z location of the 2D data to the minimum z-value of the 3D bounding box),
- if regions are overlapping, priority regulations have to be considered
- 2D data often have external visualization instructions, to achieve a correct appearance [Hempel2013].

The IFCExplorer is a platform to test the integration of different data models and different data sources, like data files or web services (see Figure 37). Future work will focus on a dynamic user interface and on establishing relations between the data models. It is not intended to store the integrated data in a unified data format.

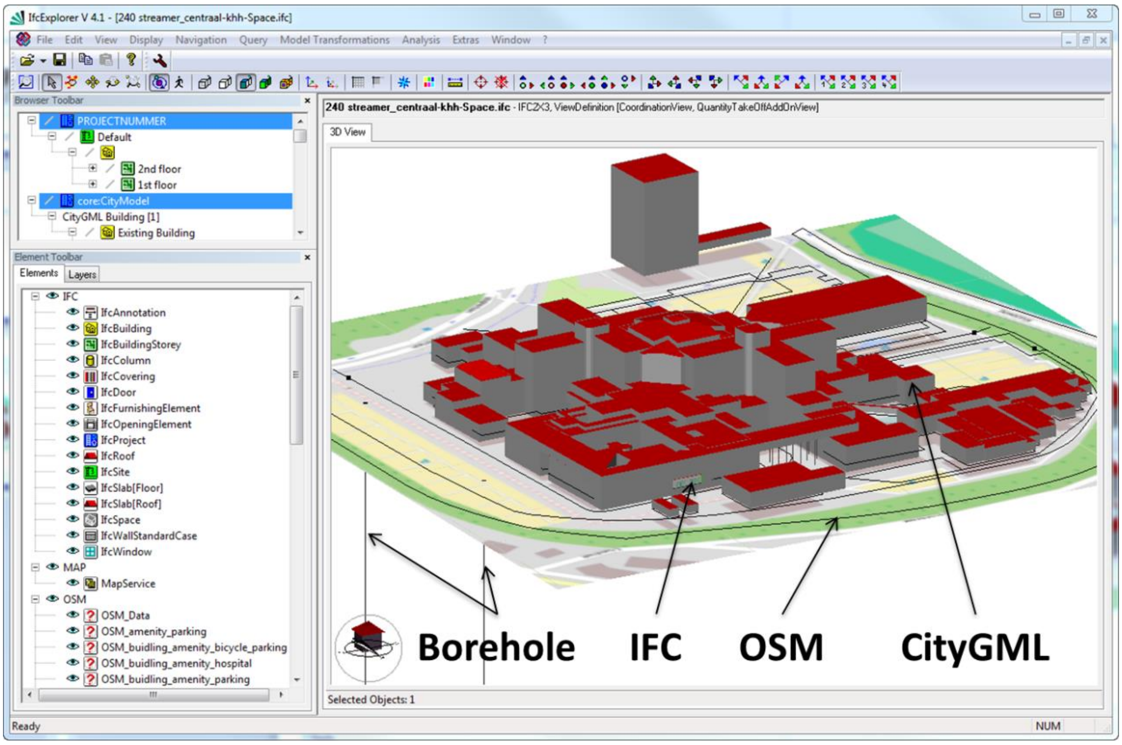

Figure 37: Example of the Rijnstate hospital, integrating different data models into one scene (source: KIT)

3.3.2 **Feature Manipulation Engine (FME) Data Inspector**

The FME Data Inspector is a visualization tool for the Feature Manipulation Engine developed by Safe Software Inc., Canada [Safe2015]. FME is an application for converting, transforming, validating, sharing and integrating data. Among the over 300 supported data formats, there are STREAMER relevant data models like CityGML and IFC.

Figure 38 shows an example of merging different GIS data sets into one scene. Beside the two 3D data sets (CityGML and 3D point cloud), two 2D data sets (native ESRI) have been merged. For each data set all relevant information, e.g. feature type, geometry and properties, can be queried. The FME Data Inspector offers all functions, including stereo mode, for a visual examination.

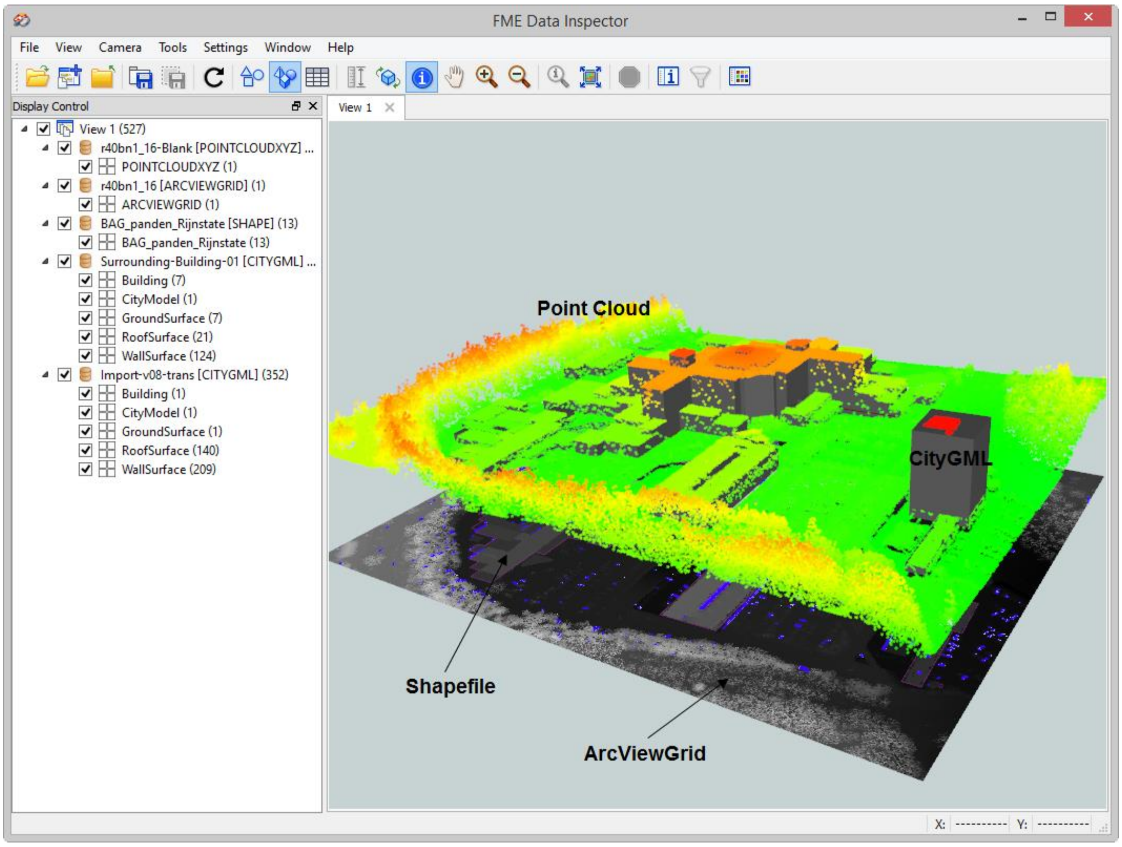

Figure 38: Example of integrating different data from Rijnstate hospital into the FME Data Inspector (source: KIT and Arnhem)

3.4 Linked Data

According to Deliverable 5.1 (Chapter 2.1.1: W3C Semantic Web Technologies and Linked (open) Data approach) linked open data can be characterized by the following rating [Berners-Lee2009]:

1. “Available on the web (whatever format) but with an open licence, to be Open Data”
2. “Available as machine-readable structured data (e.g. excel instead of image scan of a table)”
3. “as (2) plus non-proprietary format (e.g. CSV instead of excel)”
4. “All the above plus, Use open standards from W3C (RDF and SPARQL) to identify things, so that people can point at your stuff”
5. “All the above, plus: Link your data to other people’s data to provide context”

Examples for the first three levels are external links, which are offered by most data models:

- **IFC**: IFCEXTERNALREFERENCE:Location (Classification, Document, Hatch style, Surface style, Text font, Library object)
- **CityGML**: Code lists, core:ExternalReference, core:libraryObject, gen:uriAttribute, app:imageUri
- **gbXML**: ImageTexture:url, ProjectEntity:URI, GeneralGeometry
- **BCF**: Attachments, BIM-Snippet

IFCDOCUMENTREFERENCE

IFC provides the possibility to associate documents to each IFC object. The reference to the document can be a human readable hint, where the document can be found or a machine-readable link of the location of the document. If the document is on the web and public available, the data are linked open data.

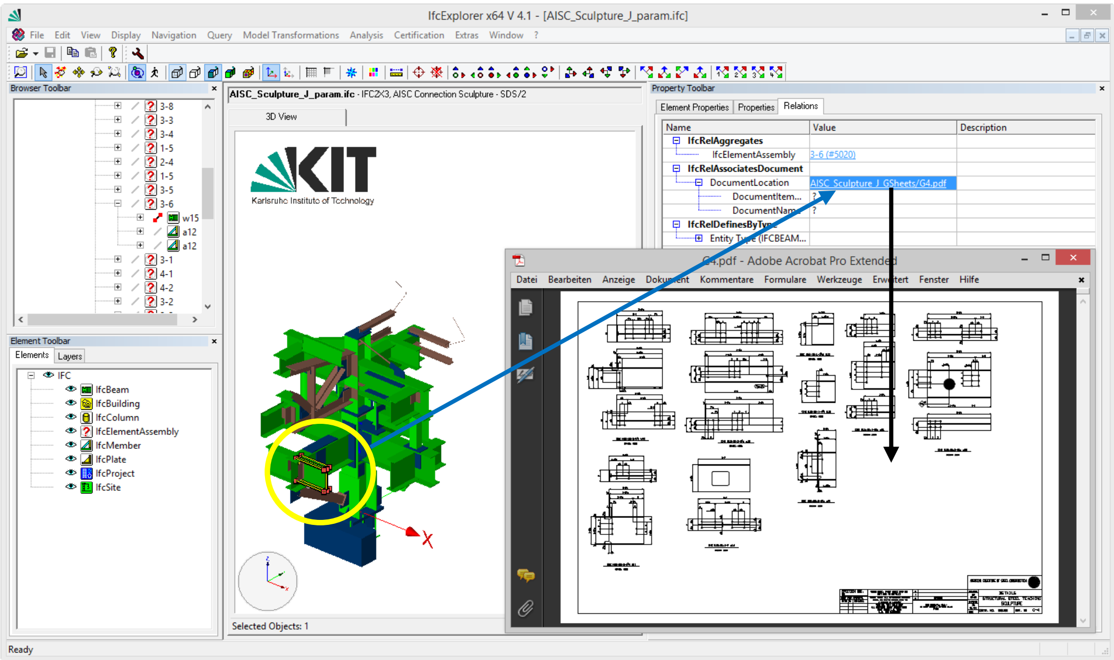

Figure 39: Example of a document reference in IFC (source: NIST, KIT)

Figure 39 shows an example of a document (detailed drawings), which is associated to an IFC building element (IFCBEAM). The relation IFCRELASSOCIATESDOCUMENT assigns the document reference to the IFC object (blue line). The IFCEXTERNALREFERENCE provides the location (for linked data an URI) of the document, which then can be opened by the importing application (black line).

IFCCLASSIFICATIONREFERENCE

If an IFC object is not referring a document (Excel, Word etc.), but is referring a classification system, a dictionary or a database entry, the IFCCLASSIFATIONREFERENCE can be used.

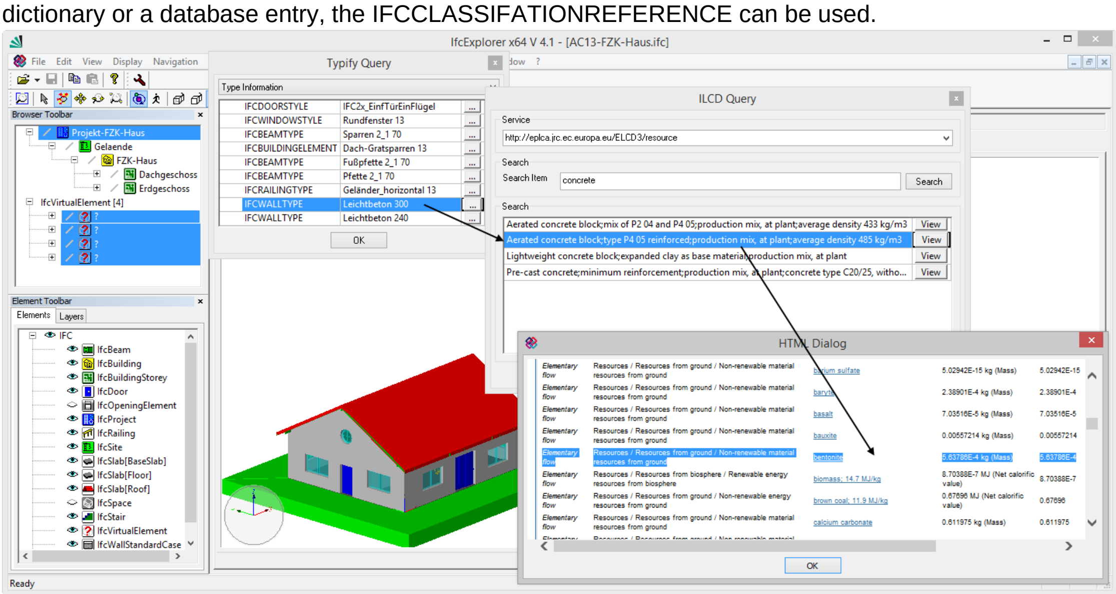

Figure 40: Linking ILCD data from the ELCD database to a material of the IFC model

One example is the access to the ELCD database of the European Community. In Figure 40, the workflow to link the data is depicted. First, a material, wall type or a specific IFC building element is selected. The link to the European reference Life Cycle Database (ELCD) is established. After selecting the required process (product) the link between IFC and ILCD is established. Now the ILCD data can be displayed. In future the corresponding link to the database will be stored in an IFCCLASSIFICATIONREFERENCE entity.

CityGML Code lists

In CityGML, the Code List concept is linked open data. Usually the “class”, “function” and “usage” properties have a codespace (URI) and a value. The value can be resolved by using external definitions or dictionaries. In the following example, the application should search in the specified simple dictionary (AbstractBuilding_function.xml) for the property value “1000”:

<bldg:function

codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_function.xml">

1000

</bldg:function>

Figure 41 shows a snapshot of the IFCExplorer [Benner2013]. In this application the link to the external dictionary is established and the corresponding text for the property value (1000 → “residential building”) is shown in the property window.

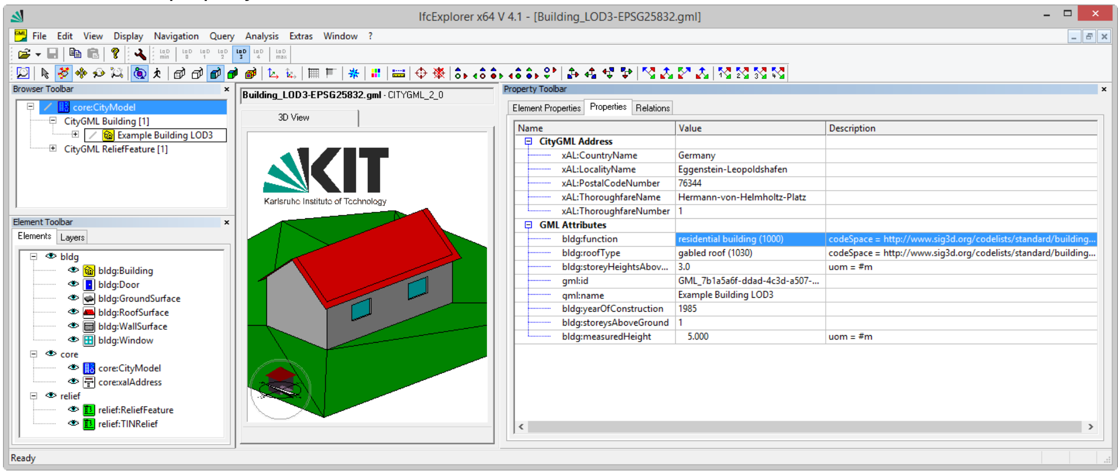

Figure 41: Example of properties “function” and “roof type” of the building with the corresponding values of the dictionary located on an open accessible server

CityGML ExternalReference

Every city object in CityGML can have an external reference in order to link any external information with CityGML features. In the example of Figure 42, the material of a wall surface (Material ADE of KIT, not published) has a reference to the German “ÖKOBAUDAT” LCA database [ÖKO2015].

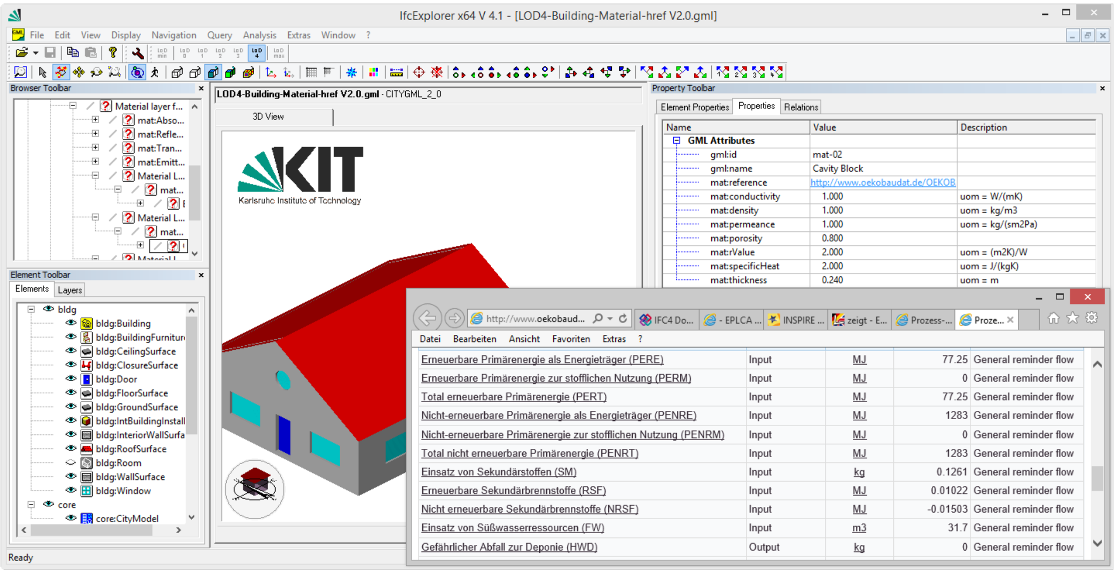

Figure 42: Link between the material (Cavity block) of a CityGML wall surface (Material ADE) and the LCA data of the process "Kalksandstein" of the German LCA database "ÖKOBAUDAT"

CityGML imageUri

If accessing textured CityGML data via Web Feature Services, it is difficult to exchange the corresponding textures. As there is no standardized archive format for CityGML, the texture files cannot simply be downloaded within an archive. The 3D City Database used and extended company virtualcitySYSTEMS [VCS2015] is able to provide a link to a web repository, where all texture files are stored.

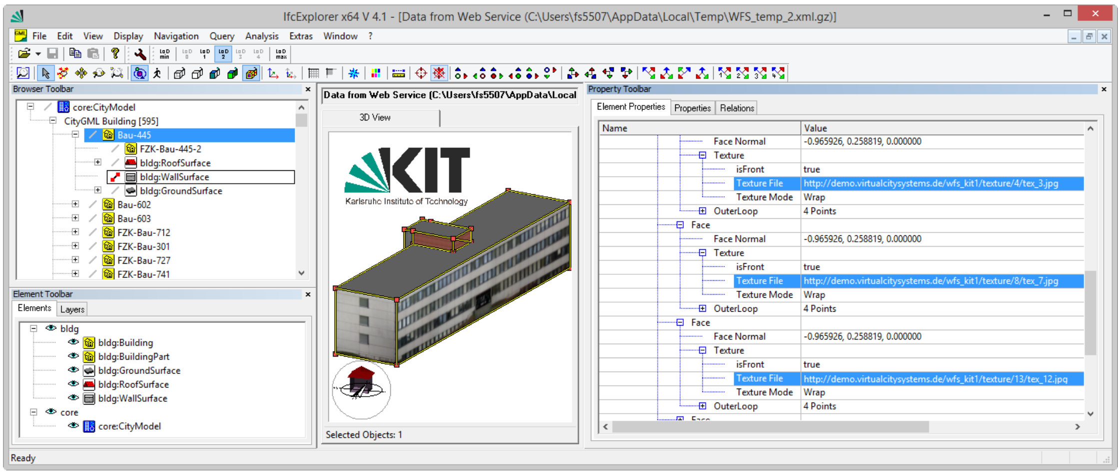

Figure 43: Example for linking texture files in CityGML. In the property window (right side) the link to the texture files are highlighted.

In Figure 43 an example of a textured model is shown. The links to the textures, which are stored on a remote server, are highlighted.

Linked Data using open standards from W3C and providing context

Examples for level 4 and 5 are not yet available within the STREAMER consortium. In the research area, there are several projects proposing linked data for different applications within the building industry. The project V-Con [V-Con2015] for example, which interacts with the Dutch initiative CB-NL [CB-NL2015], has an example based upon the CB-NL semantic web ontology.

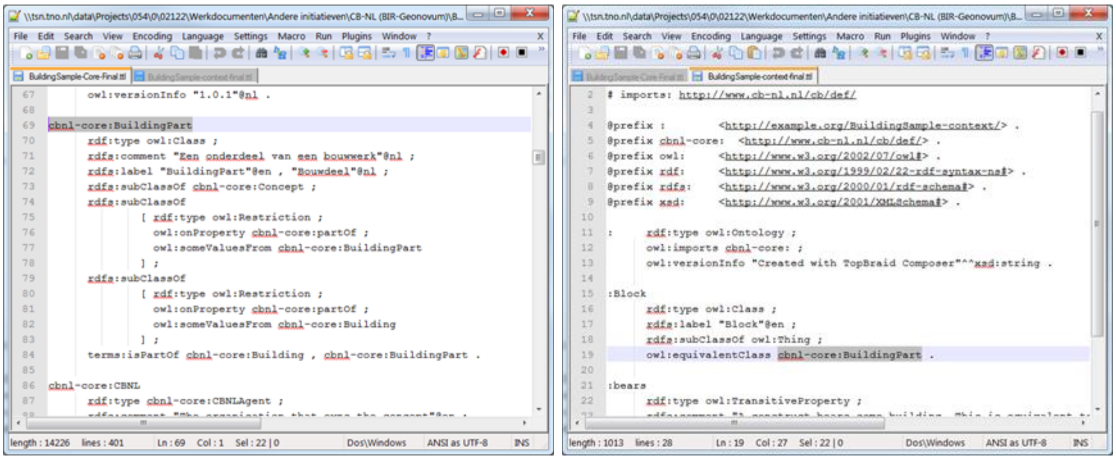

Figure 44: Example for linking data in owl files. Define an equivalent class based upon an existing class in the CB-NL standard.

The left window in Figure 44 shows the CB-NL ontology containing a class BuildingPart. On the right, a new ontology is created which contains a new class called Block, being equivalent to the BuildingPart class. Both ontologies use a prefix instead of a full URI when describing the RDF-triples. So “cbnl-core:BuildingPart” is the short-hand notation for “http://www.cb-nl.nl/cb/def/BuildingPart”.

The example shows how to create an ontology and how this ontology relates to an existing ontology, but it could also extend an existing ontology in a similar way by linking to an external class by using the “rdfs:subClassOf” property. Although this example addresses typologies, instances can equally be linked to externally defined instances. This will be comparable to the examples mentioned before (linking objects instances to external material instances).

4. Recommendations and conclusion

Chapter 2, introduces modelling languages, data models, data formats, and standardised web services, which might be relevant to STREAMER. Modelling languages and the standardised web services are not discussed in this document. Within STREAMER, modelling languages are not subject of research. If standardized web services are to be used, there is no alternative to OGC services for GIS application and bSI services (BIMsie, BCF 2.0 RESTful API) for BIM.

Regarding data models, STREAMER probably has to consider more than one standard. Depending on data availability and project phase, different data models might be deployed. The models can be evaluated using the following criteria:

- Life cycle phases for which the model is designed;
- Scope of the model;
- Semantic and geometrical complexity of the model;
- Software support for importing and exporting the model.

Since 1985, projects have been undertaken to develop a so-called integrated building model [Bretthauer2001]. Today, IFC is the only standardized model for buildings, which claims to cover the complete life cycle. Accordingly, the IFC model is very comprehensive and supports nearly 770 entities and nearly 410 property sets (IFC4). With IFC4, the building model can have arbitrary geospatial references and generalized civil engineering (e.g. pavements) and geographical elements (e.g. roads, trees). Usually, not all the geometry is described explicitly. Hence, the importing application needs basic geometrical functions at least. The import and export of IFC is supported by free and commercial tools, but needs more experience than e.g. XML. Currently, IFC is supported by all major CAAD vendors (see chapter 6.1), and most of them have already been certified or are in an on-going certification process performed by buildingSmart (bSI).

Theoretically, **IFC might be able to cover all processes**, which are planned within STREAMER.

One important reason, why this approach does not work in reality, is that when generating a digital representation of buildings, the complete life cycle is not fully considered in an integrative way. There are many actors in many domains with many software applications, which have their own view of the building. All want to have models, which exactly represent the information required and exactly speak their languages. This leads to domain-specific, specialized data models, like gbXML or ILCD. On the other hand, it is not easy to synchronize two major domains, such as the GIS and BIM worlds. The responsible standardization organizations (OGC and bSI) started nearly at the same time (20 years ago) to independently develop standards for their domains. Of course, software applications of the GIS world most likely support OGC standards, while BIM applications provide better support for bSI standards. For designing buildings, it is essential to consider the neighbourhood to obtain a holistic view on the project. The main topic of STREAMER, “energy-efficient buildings integrated in the neighbourhood energy systems” reflects this situation. Therefore, both worlds, GIS and BIM, including their specific standards, are of similar relevance to STREAMER.

Practically, **STREAMER has to consider using different data models in a combined manner** in order to realize the intended workflow.

One strategy can be to use the most appropriate data model or data format for a specific task or process. If a data model or a data format supports a process in an appropriate way and if the resulting data are not fed back to the original model, the task can be performed to full satisfaction.

If a process requires more than one data model, for instance, when considering a detailed building model in its neighbourhood, a so-called hybrid approach is required. In this approach, data are kept in the original models and:

- enriched by other information sources,
- converted into the requested target models,
- integrated into a single software application, or
- linked,

by the corresponding software tools, if necessary.

Examples of all four processes mentioned above are given in chapter 3. Enriching data is illustrated by two cases of enriching the material properties of IFC. In both cases, the complete information is not expected to be provided by the architect, but has to be added by the corresponding experts. In order to bridge the gap between GIS and BIM worlds, models can be converted. A typical example is to generalize a detailed IFC model to a certain LoD and save it as a CityGML model. If an application covers more than one domain and is able to import different models, further analysis and simulations can be performed on the integrated model. The most advanced method is the linked data approach.

As IFC is the only openBIM data model, which covers the whole life cycle of the building and which can also be used in the construction process, it is recommended for use as a basis for all STREAMER processes. In general, this means that IFC is used for designing the new or refurbished building. Depending on the deployed software application and on additionally required information, models can be enriched, converted, or linked. The results of the modelling processes should be preserved by attaching the data to the IFC model. This can be done by converting the results into IFC entities, user-defined IFC properties, or by linking the results to the IFC model.

If different data models describe the same real world object (e.g. a building), it is likely that similar or even the same information is stored multiple times. If this information is not aligned, this redundancy can cause discrepancies, which have to be solved.

The management of different data models including data linking, web services, and preserving data consistency, is difficult to perform manually. Therefore, the complete building life cycle needs to be supported by a Product Lifecycle Management (PLM) system.

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6. Appendix

6.1 Table of interfaces for STREAMER relevant applications

The following table lists the interoperability capabilities of applications, which are used within the STREAMER project and which are at least partly tested from the STREAMER consortium. Applications, which are not promoting open data models in their product information (e.g. TRNSYS, BriefBuilder) or which are only available as plug-ins (e.g. Sefaira), are not lists in the table, even if they are used by project partners.

Application	IFC	gbXML	CityGML	BCF	others
BIM					
ArchiCAD	Import / Export			Import / Export	
Autodesk Architecture	Import / Export	Export			
Autodesk REVIT Architecture	Import / Export	Import / Export		Import / Export[1]	
Autodesk REVIT MEP	Import / Export			Import / Export	
Allplan	Import / Export				
Data Design System	Import / Export	Import			VDI3805
dRofus	Export				
IDA ICE	Import[2]				
IES	Import	Import			
DEMO RE Suite	Import		Import	Import	
Sketchup Pro	Export		Import / Export[3]		
Solibri	Import			Import / Export	
Vabi	Import				
GIS					
ArcGIS			Import / Export		
Autodesk Infraworks			Import		LandXML
FEM	Import / Export		Import / Export		

[1] BCFier Plugin (http://matteocominetti.com/bcf-revit-plugin/)

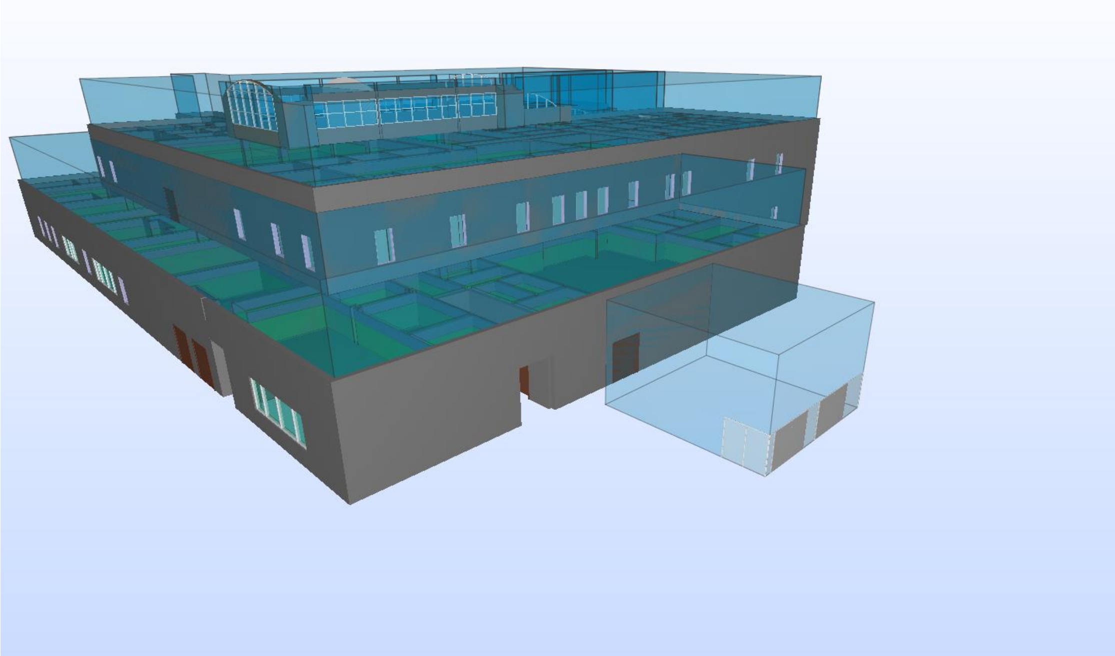
[2] Tested by NCC

[3] GEORES CityGML Plugins (http://www.geores.de/geoResPlugins.html)

6.2 Medical Clinic IFC model from the National Institute of BUILDING SCIENCE and buildingSMART

The National Institute of BUILDING Science (NIBS) and buildingSMART (bSI) have created BIM examples for different building types. One example is medical clinic (http://www.nibs.org/?page=bsa_commonbimfiles&terms=%22clinic%22#project3). Besides several data sources like spreadsheets and drawings, there are also different IFC models available. Here, only the IFC models according the Coordination Model View (version 1.0) are considered.

Architectural Model



The architectural model (Clinic_A_20110906.ifc, 17.7 MB, snapshot: Solibri 9.5) is subdivided in four storeys and contains the following building elements (total number 3293):

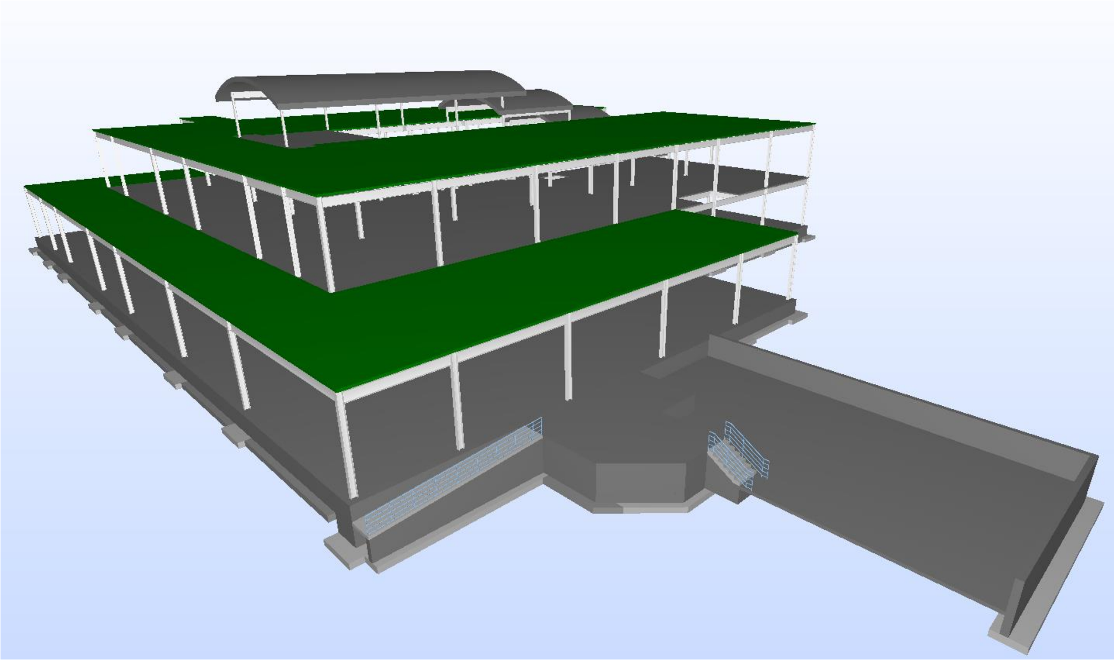
IfcCovering	250	IfcRailing	9
IfcDoor	254	IfcSlab[Landing]	3
IfcCurtainWall	31	IfcSpace	269
IfcFlowTerminal	102	IfcStair	3
IfcFurnishingElement	118	IfcStairFlight	6
IfcMember	534	IfcWall	15
IfcOpeningElement	403	IfcWallStandardCase	1065
IfcPlate	172	IfcWindow	58

The spatial structure elements of the architectural model have the following GUIDs:

IfcProject	3eM8WbY_59RR5TDWry5aRV
IfcSite	3eM8WbY_59RR5TDWry5aRT
IfcBuilding	3eM8WbY_59RR5TDWry5aRU

It is remarkable, that slabs and roofs are not part of the architectural model and that the architectural model contains flow terminal. The flow terminals in this model are representing e.g. the elevator, fire extinguisher, mirrors, towel dispenser and grab bars. The furnishing elements are used to model cabinets and counters. The model contains space boundaries, but as the slabs and roofs are missing, all horizontal boundaries are not available

Structural Model



The structural model (Clinic_S_20110715.ifc, 19 MB, snapshot: Solibri 9.5) is also subdivide in four storeys. The names of the storeys are identical with the names of the architectural model. The model contains the following building elements:

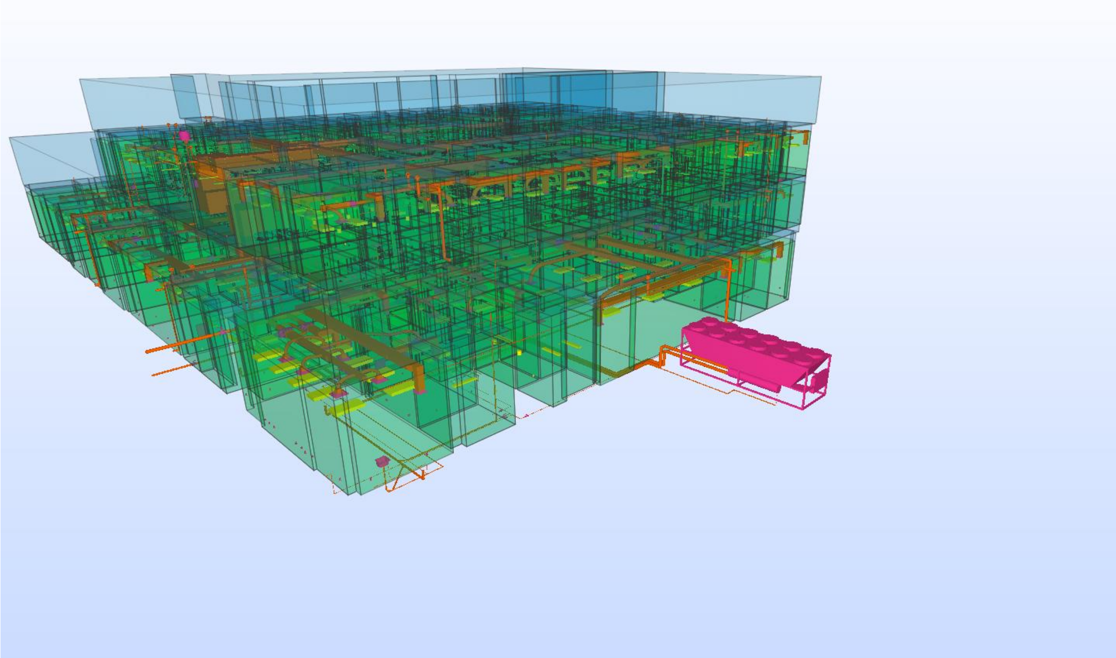
IfcBeam	738	IfcRoof	12
IfcColumn	195	IfcSlab[Floor]	6
IfcFooting	96	IfcSlab[Roof]	7
IfcOpeningElement	7	IfcStair	1
IfcRailing	3	IfcStairFlight	1
IfcRamp	1	IfcWallStandardCase	26
IfcRampFlight	1		

The spatial structure elements of the structural model have the following GUIDs:

IfcProject	050AJY0PT2cvfLDNPENU2_
IfcSite	050AJY0PT2cvfLDNPENU2y
IfcBuilding	050AJY0PT2cvfLDNPENU2$

All slabs and roofs are contained in the structural model. The model contains no spaces and therefore also no space boundaries.

MEP (Mechanical, Electrical and Plumbing) Model



The MEP model (Clinic_MEP_20110906.ifc, 202 MB, snapshot: Solibri 9.5) is also subdivided in four storeys. In contrast to the architectural and structural models, the names of storeys are not identical. The model contains the following building elements:

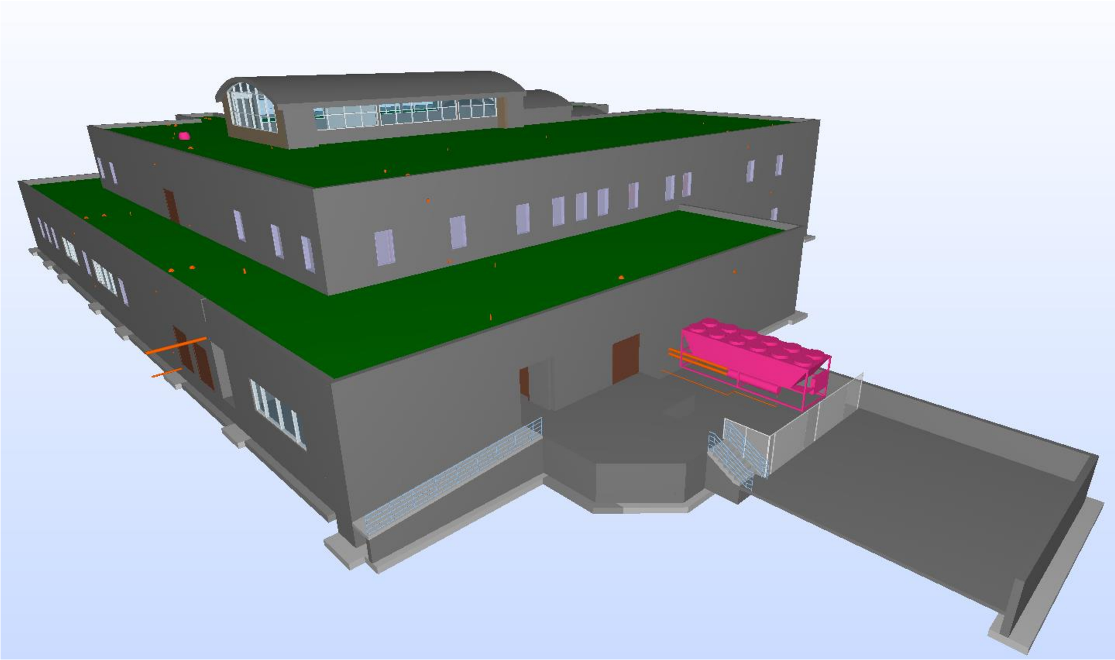
IfcEnergyConversionDevice	3	IfcFlowSegement	5952
IFCFlowController	173	IfcFlowTerminal	3053
IfcFlowFitting	6693	IfcSpace	526
IfcFlowMovingDevice	137		

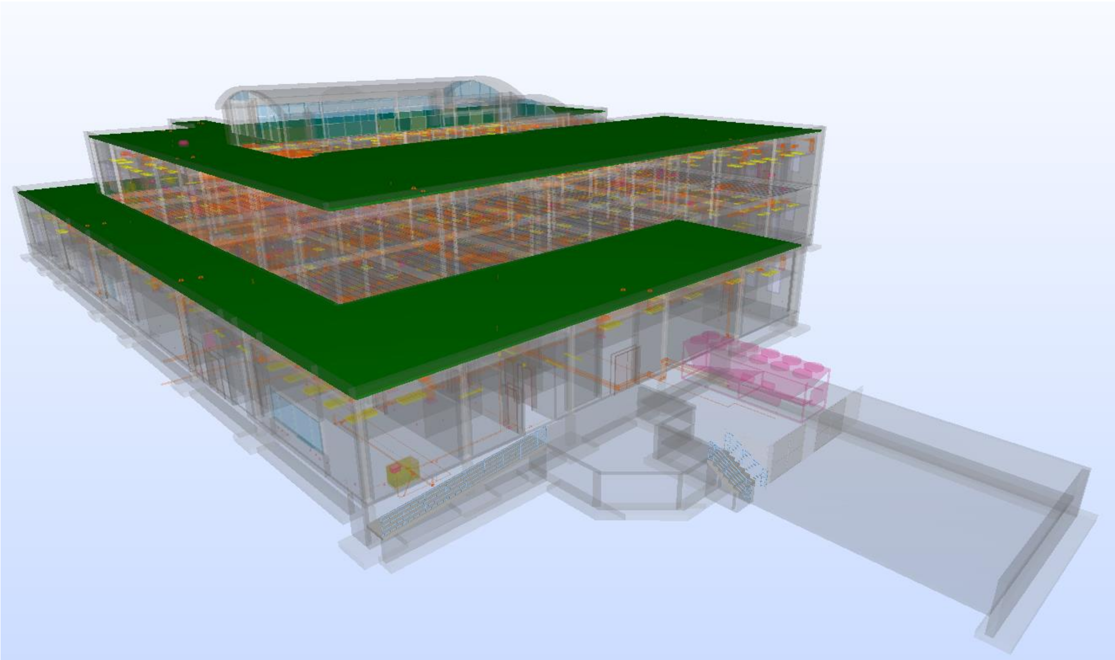
The spatial structure elements of the MEP model have the following GUIDs:

IfcProject	1VB9G8xuL3MArqCPnBKZuI
IfcSite	1VB9G8xuL3MArqCPnBKZuG
IfcBuilding	1VB9G8xuL3MArqCPnBKZuJ

It is noticeable that the MEP model contains more spaces than the architectural model. The topology of the pipe network is not modelled (no IfcPort) and the MEP elements are not grouped (no IfcSystem). Most of the MEP elements are assigned to a space. It seems that all MEP elements are assigned to an object type (e.g. IfcDuctFittingType, .IfcDuctFittingType).

Complete Model





As the partial models (architectural, structural and MEP) do not have identical GUIDs for IfcProject, IfcSite, IfcBuilding and IfcBuildingStorey, and not all spatial structure elements have the same names, a real merging into one resulting building is hardly possible. All tested application for merging the data are creating three buildings with the corresponding storeys.

6.3 Spatial decomposition of buildings

In the following tables, the capabilities of building models regarding spatial decomposition and grouping of buildings and building elements are listed. Each spatial element (e.g. building, storey) is subdivided regarding the aggregation level (complex, element, partial) (see first table).

Besides the decomposition with spatial elements, which might be hierarchical and might have placements and shape representations, there are grouping elements (see second table), which usually are logical collections of objects.

Spatial Element	IFC2x3	IFC4	gbXML	CityGML
Site				
Complex	Yes	Yes	No	No
Element	Yes	Yes	Yes (Campus)	No
Partial	Yes	Yes	No	No
Building				
Complex	Yes	Yes	No	No
Element	Yes	Yes	Yes	Yes
Partial	Yes	Yes	No	Yes (BuildingPart)
Storey				
Complex	Yes	Yes	No	No
Element	Yes	Yes	Yes	No
Partial	Yes	Yes	No	No
Zone				
Complex	No	No	No	No
Element	No	Yes (IFCSPATIALZONE)	No	No
Partial	No	NO	No	No
Space				
Complex	Yes	Yes	No	No
Element	Yes	Yes	Yes	Yes (Room)
Spatial	Yes	Yes	No	No

Grouping Element	IFC2x3	IFC4	gbXML	CityGML
Group				
Group	Yes	Yes	No	Yes
System	Yes	Yes	Yes (e.g. AirLoop)	No
Zone	Yes (IFCZONE)	Yes (IFCZONE)	Yes (Zone)	No

6.4 Material properties

The following table lists the material properties from IFC2x3, IFC4 and gbXML. As CityGML has no material properties, (CityGML X3DMaterial has only properties for the appearance of a surface) it is not part of the table.

While in IFC all material properties are assigned to IFCMATERIAL, gbXML assign properties to gbxml:Material, gbxml:Construction and WindowType.

IFC2x3	IFC4	gbXML
IfcProductsOfCombustionProperties	**Pset_MaterialCombustion**	
SpecificHeatCapacity	SpecificHeatCapacity	SpecificHeat (gbXML:Material)
N20Content	N20Content	
COContent	COContent	
CO2Content	CO2Content	
IfcGeneralMaterialProperties	**Pset_MaterialCommon**	
MolecularWeight	MolecularWeight	
Porosity	Porosity	Porosity (gbXML:Material)
MassDensity	MassDensity	Density (gbXML:Material)
	Pset_MaterialEnergy	
	ViscosityTemperatureDerivative	
	MoistureCapacityThermal Gradient	
	ThermalConductivity TemperatureDerivative	
	SpecificHeatTemperature Derivative	
	VisibleRefractionIndex	
	SolarRefractionIndex	
	GasPressure	
IfcFuelProperties	**Pset_MaterialFuel**	
CombustionTemperature	CombustionTemperature	
CarbonContent	CarbonContent	
LowerHeatingValue	LowerHeatingValue	
HigherHeatingValue	HigherHeatingValue	
IfcHygroscopicMaterialProperties	**Pset_MaterialHygroscopic**	
UpperVaporResistanceFactor	UpperVaporResistanceFactor	
LowerVaporResistanceFactor	LowerVaporResistanceFactor	
IsothermalMoistureCapacity	IsothermalMoistureCapacity	
VaporPermeability	VaporPermeability	
MoistureDiffusivity	MoistureDiffusivity	
IfcMechanicalMaterialProperties	**Pset_MaterialMechanical**	
DynamicViscosity	DynamicViscosity	
YoungModulus	YoungModulus	
ShearModulus	ShearModulus	
PoissonRatio	PoissonRatio	
ThermalExpansionCoefficient	ThermalExpansionCoefficient	
IfcOpticalMaterialProperties	**Pset_MaterialOptical**	
VisibleTransmittance	VisibleTransmittance	Transmittance (gbXML:Construction, gbxml:WindowType)
SolarTransmittance	SolarTransmittance	Transmittance (gbXML:Construction, gbxml:WindowType)
ThermalIrTransmittance	ThermalIrTransmittance	Transmittance (gbXML:Construction gbxml:WindowType)
ThermalIrEmissivityBack	ThermalIrEmissivityBack	Absorptance (gbXML:Construction) Emittance (gbxml:WindowType)
ThermalIrEmissivityFront	ThermalIrEmissivityFront	Absorptance (gbXML:Construction) Emittance (gbxml:WindowType)

VisibleReflectanceBack	VisibleReflectanceBack	Reflectance (gbXML:Construction, gbxml:WindowType)
VisibleReflectanceFront	VisibleReflectanceFront	Reflectance (gbXML:Construction, gbxml:WindowType)
SolarReflectanceFront	SolarReflectanceBack	Reflectance (gbXML:Construction, gbxml:WindowType)
SolarReflectanceBack	SolarReflectanceFront	Reflectance (gbXML:Construction, gbxml:WindowType)
IfcThermalMaterialProperties	**Pset_MaterialThermal**	
SpecificHeatCapacity	SpecificHeatCapacity	SpecificHeat (gbXML:Material)
BoilingPoint	BoilingPoint	
FreezingPoint	FreezingPoint	
ThermalConductivity	ThermalConductivity	
IfcWaterProperties	**Pset_MaterialWater**	
IsPotable	IsPotable	
Hardness	Hardness	
AlkalinityConcentration	AlkalinityConcentration	
AcidityConcentration	AcidityConcentration	
ImpuritiesContent	ImpuritiesContent	
DissolvedSolidsContent	DissolvedSolidsContent	
PHLevel	PHLevel	
	Pset_MaterialConcrete	
	CompressiveStrength	
	MaxAggregateSize	
	AdmixturesDescription	
	Workability	
	WaterImpermeability	
	ProtectivePoreRatio	
	Pset_MaterialSteel	
	YieldStress	
	UltimateStress	
	UltimateStrain	
	HardeningModule	
	ProportionalStress	
	PlasticStrain	
	Relaxations	
	Pset_MaterialWood	
	Species	
	StrengthGrade	
	AppearanceGrade	
	Layup	
	Layers	
	Plies	
	MoistureContent	
	DimensionalChangeCoefficient	
	ThicknessSwelling	
	Pset_MaterialWoodBasedBeam	
	Mechanical properties for wood-based beam-like products	
	Pset_MaterialWoodBasedPanel	
	Mechanical properties for wood-based panel-like products	
		R-value (gbXML:Material)
		Permeance (gbXML:Material)
		Albedo (gbXML:Construction)
		Roughness (gbXML:Construction)

6.5 Environmental impact parameter

The table below indicates a comparison between environmental impact parameter from IFC (Version 4) and ILCD.

IFC4	ILCD
Pset_EnvironmentalImpactIndicators	
Reference	
FunctionalUnitReference	
Unit	
LifeCyclePhase	
ExpectedServiceLife	
TotalPrimaryEnergyConsumptionPerUnit	
WaterConsumptionPerUnit	
HazardousWastePerUnit	
NonHazardousWastePerUnit	
ClimateChangePerUnit	
AtmosphericAcidificationPerUnit	
RenewableEnergyConsumptionPerUnit	
NonRenewableEnergyConsumptionPerUnit	
ResourceDepletionPerUnit	
InertWastePerUnit	
RadioactiveWastePerUnit	
StratosphericOzoneLayerDestructionPerUnit	
PhotochemicalOzoneFormationPerUnit	
EutrophicationPerUnit	
Pset_EnvironmentalImpactValues	**LCIAImpactCategoryValues**
TotalPrimaryEnergyConsumption	
WaterConsumption	
HazardousWaste	
NonHazardousWaste	
ClimateChange	Climate change
AtmosphericAcidification	Acidification
RenewableEnergyConsumption	
NonRenewableEnergyConsumption	
ResourceDepletion	
InertWaste	
RadioactiveWaste	
StratosphericOzoneLayerDestruction	Ozone depletion
PhotochemicalOzoneFormation	Photochemical ozone creation
Eutrophication	Terrestrial Eutrophication Aquatic Eutrophication
	Land use

6.6 INSPIRE themes

The following table lists the all themes, which are specified in Annex I, II and III including the definition of each theme and a link to the online documentation.

	Definition	Documentation
ANNEX I		
1 Coordinate reference systems	Systems for uniquely referencing spatial information in space as a set of coordinates (x, y, z) and/or latitude and longitude and height, based on a geodetic horizontal and vertical datum.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_RS_v3.2.pdf
2 Geographical grid systems	Harmonised multi-resolution grid with a common point of origin and standardised location and size of grid cells.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_GG_v3.1.pdf
3 Geographical names	Names of areas, regions, localities, cities, suburbs, towns or settlements, or any geographical or topographical feature of public or historical interest.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_GN_v3.1.pdf
4 Administrative units	Units of administration, dividing areas where Member States have and/or exercise jurisdictional rights, for local, regional and national governance, separated by administrative boundaries.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_AU_v3.1.pdf
5 Addresses	Location of properties based on address identifiers, usually by road name, house number, postal code.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_AD_v3.1.pdf
6 Cadastral parcels	Areas defined by cadastral registers or equivalent.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_CP_v3.1.pdf
7 Transport networks	Road, rail, air and water transport networks and related infrastructure. Includes links between different networks. Also includes the trans-European transport network as defined in Decision No 1692/96/EC of the European Parliament and of the Council of 23 July 1996 on Community Guidelines for the development of the trans-European transport network (1) and future revisions of that Decision.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_TN_v3.2.pdf
8 Hydrography	Hydrographic elements, including marine areas and all other water bodies and items related to them, including river basins and sub-basins. Where appropriate, according to the definitions set out in Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (2) and in the form of networks.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_HY_v3.1.pdf
9 Protected sites	Area designated or managed within a framework of international, Community and Member States' legislation to achieve specific conservation objectives.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_PS_v3.2.pdf
ANNEX II		
1 Elevation	Digital elevation models for land, ice and ocean surface. Includes terrestrial elevation, bathymetry and shoreline.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_EL_v3.0.pdf
2 Land cover	Physical and biological cover of the earth's surface including artificial surfaces, agricultural areas, forests, (semi-)natural areas, wetlands, water bodies.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_LC_v3.0.pdf

3 Orthoimagery	Geo-referenced image data of the Earth's surface, from either satellite or airborne sensors.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_OI_v3.0.pdf
4 Geology	Geology characterised according to composition and structure. Includes bedrock, aquifers and geomorphology.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_GE_v3.0.pdf
ANNEX III		
1 Statistical units	Units for dissemination or use of statistical information.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_SU_v3.0.pdf
2 Buildings	Geographical location of buildings.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_BU_v3.0.pdf
3 Soil	Soils and subsoil characterised according to depth, texture, structure and content of particles and organic material, stoniness, erosion, where appropriate mean slope and anticipated water storage capacity.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_SO_v3.0.pdf
4 Land use	Territory characterised according to its current and future planned functional dimension or socio-economic purpose (e.g. residential, industrial, commercial, agricultural, forestry, recreational).	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_LU_v3.0.pdf
5 Human health and safety	Geographical distribution of dominance of pathologies (allergies, cancers, respiratory diseases, etc.), information indicating the effect on health (biomarkers, decline of fertility, epidemics) or well-being of humans (fatigue, stress, etc.) linked directly (air pollution, chemicals, depletion of the ozone layer, noise, etc.) or indirectly (food, genetically modified organisms, etc.) to the quality of the environment.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_HH_v3.0.pdf
6 Utility and governmental services	Includes utility facilities such as sewage, waste management, energy supply and water supply, administrative and social governmental services such as public administrations, civil protection sites, schools and hospitals.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_US_v3.0.pdf
7 Environmental monitoring Facilities	Location and operation of environmental monitoring facilities includes observation and measurement of emissions, of the state of environmental media and of other ecosystem parameters (biodiversity, ecological conditions of vegetation, etc.) by or on behalf of public authorities.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_EF_v3.0.pdf
8 Production and industrial facilities	Industrial production sites, including installations covered by Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (1) and water abstraction facilities, mining, storage sites.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_PF_v3.0.pdf
9 Agricultural and aquaculture facilities	Farming equipment and production facilities (including irrigation systems, greenhouses and stables).	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_AF_v3.0.pdf
10 Population distribution and demography	Geographical distribution of people, including population characteristics and activity levels, aggregated by grid, region, administrative unit or other analytical unit.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_PD_v3.0.pdf
11 Area management / restriction / regulation zones & reporting units	Areas managed, regulated or used for reporting at international, European, national, regional and local levels. Includes dumping sites, restricted areas around drinking water sources, nitrate-vulnerable zones, regulated fairways at sea or large inland waters, areas for the dumping of waste, noise restriction	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_AM_v3.0.pdf

	zones, prospecting and mining permit areas, river basin districts, relevant reporting units and coastal zone management areas.	
12 Natural risk zones	Vulnerable areas characterised according to natural hazards (all atmospheric, hydrologic, seismic, volcanic and wildfire phenomena that, because of their location, severity, and frequency, have the potential to seriously affect society), e.g. floods, landslides and subsidence, avalanches, forest fires, earthquakes, volcanic eruptions.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_NZ_v3.0.pdf
13 Atmospheric conditions	Physical conditions in the atmosphere. Includes spatial data based on measurements, on models or on a combination thereof and includes measurement locations.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_AC-MF_v3.0.pdf
14 Meteorological geographical features	Weather conditions and their measurements; precipitation, temperature, evapotranspiration, wind speed and direction.	-
15 Oceanographic geographical features	Physical conditions of oceans (currents, salinity, wave heights, etc.).	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_OF_v3.0.pdf
16 Sea regions	Physical conditions of seas and saline water bodies divided into regions and sub-regions with common characteristics.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_SR_v3.0.pdf
17 Bio-geographical regions	Areas of relatively homogeneous ecological conditions with common characteristics.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_BR_v3.0.pdf
18 Habitats and biotopes	Geographical areas characterised by specific ecological conditions, processes, structure, and (life support) functions that physically support the organisms that live there. Includes terrestrial and aquatic areas distinguished by geographical, abiotic and biotic features, whether entirely natural or semi-natural.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_HB_v3.0.pdf
19 Species distribution	Geographical distribution of occurrence of animal and plant species aggregated by grid, region, administrative unit or other analytical unit.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_SD_v3.0.pdf
20 Energy Resources	Energy resources including hydrocarbons, hydropower, bio-energy, solar, wind, etc., where relevant including depth/height information on the extent of the resource.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_ER_v3.0.pdf
21 Mineral Resources	Mineral resources including metal ores, industrial minerals, etc., where relevant including depth/height information on the extent of the resource.	http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_MR_v3.0.pdf

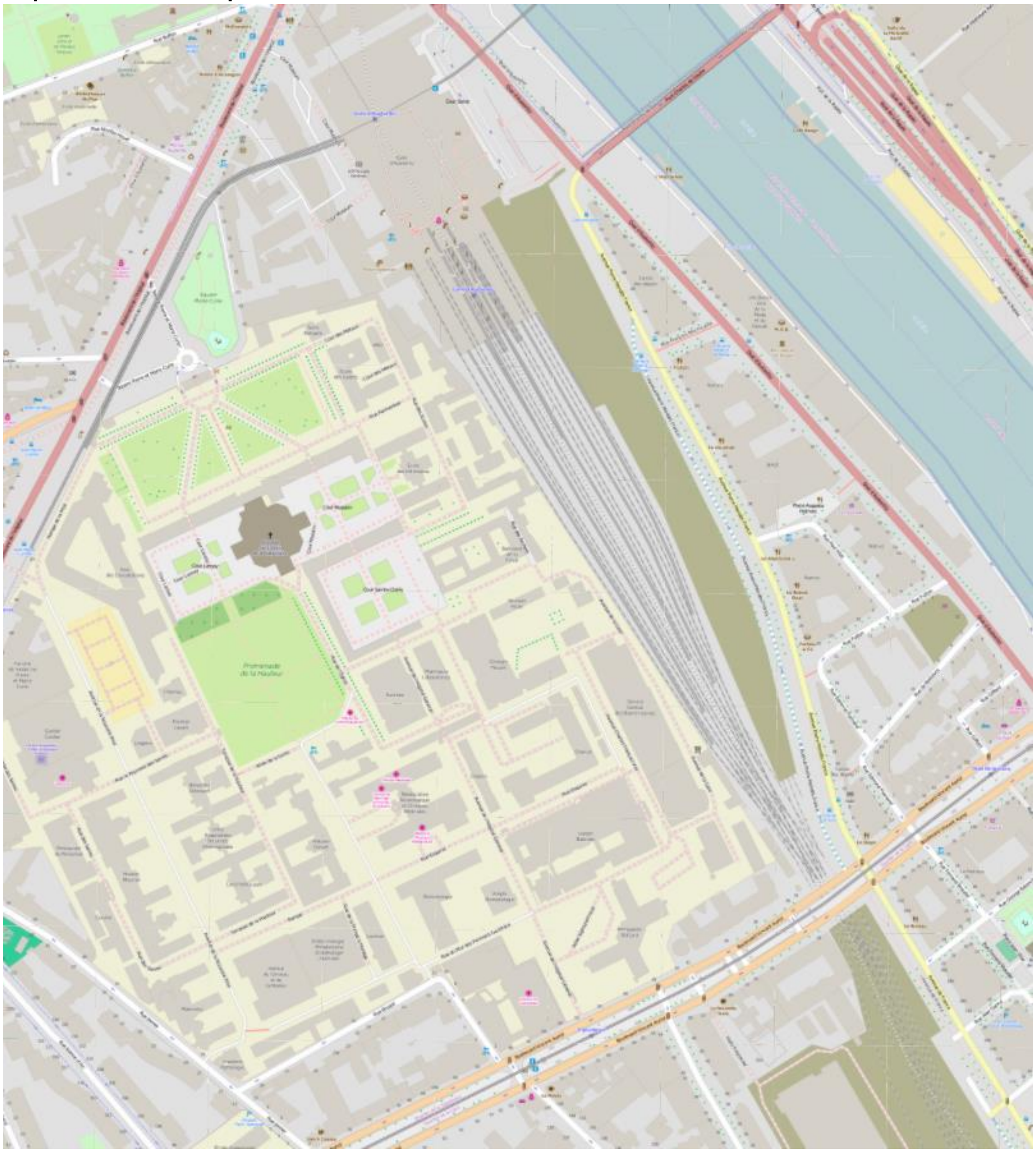
6.7 OpenStreeMap data of the demonstration sites

Azienta Ospedaliera Universitaria Careggi Florence

Streamer relevant objects:

Tree	606
Bus stop	18
Subway	0
Parking	16
Taxi	1
Foot way	48
Parks and recreation grounds	11
River	1
Natural water	0

Hôpital de la Pitié Salpêtrière



Streamer relevant objects:

Tree	944
Bus stop	15
Subway	9
Parking	6
Taxi	1
Foot way	70
Parks and recreation grounds	22
River	1
Natural water	0

Rijnstate Ziekenhuis

Streamer relevant objects:

Tree	0
Bus stop	4
Subway	0
Parking	10
Taxi	0
Foot way	19
Parks and recreation grounds	2
River	0
Natural water	2

The Rotherham NHS Foundation Trust Rotherham Hospital

Streamer relevant objects:

Tree	0
Bus stop	5
Subway	0
Parking	0
Taxi	0
Foot way	19
Parks and recreation grounds	0
River	0
Natural water	0