Streamer
European research on energy-efficient healthcare districts

D5.1

State-of-the-art review of advancements and challenges in ontology research

Deliverable Report: D5.1 - Final

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State-of-the-art review of advancements and challenges in ontology research

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Colophon

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Publishable executive summary

This document, Deliverable 5.1 “*State-of-the-art review of advancements and challenges in ontology research*” aims at defining the future directions of development work in Streamer in regard to Building Information Modelling (BIM) and Geographic Information System (GIS) information model usages in hospital design. The state-of-the-art review focusses on (1) the technology advances in the area of information management, leading to modern data schemas for BIM and GIS, the next generation ontologies following semantic web technology, and IT tools that can be used by developers and well-informed users to create and access such ontologies. And (2) it highlights the scenarios and data-flow needs arising from the Streamer hospital use cases.

The conclusions are based on a medium term view on developments reaching to novel, but still practical results within a two to three year time frame. The main recommendations are:

- Focus is on quality of BIM and GIS data for supporting the assessment of quantifiable key performance indicators, such as energy efficiency, efficient space layout, or best match of the client’s programme of requirements.
- Key factors are checkable BIM and GIS submissions that can be validated against the stated information requirements and applicable codes (for usability, permits, or best practice).
- Explicit definitions of information requirements identify the necessary information content needed to perform several tasks (such as energy simulation) or checks (such as accessibility rules),
- The best option is the hybrid use of existing BIM and GIS tools, standards and formats, enhanced by formal representations of information requirements and open definition of checkable rules, with novel solutions deriving from semantic web technologies, to encode more complex knowledge and codes.

Those recommendations are confirmed by the results of the state-of-the-art in ontological research, information management and collaboration support, and toolset available for developers and users. Latest developments in semantic web technology and linked open data approaches are seen as being suitable to enhance and complement an information management/collaboration support based on open standards, in particular IFC and CityGML. Also these standards shall be further enhanced by an additional layer that enables quality checks of data described by these formats. Here the formal specification of Model View Definitions (MVD) has been identified as an important intermediate step leading to mvdXML that allows for checking IFC-based BIM submissions against the stated information requirements.

The objectives for further work in Streamer in the direction outlined by the recommendations are (1) improve BIM and GIS information management, including work flow specific exchanges, data requirement definitions, and quality checks, (2) interlink various information sources, including references to linked open data on the web, and (3) encode additional knowledge for more comprehensive code checking and better parameterization of design solutions.

List of acronyms and abbreviations

- ADE: Application Domain Extension
- API: Application Programming Interface
- BCF: BIM Collaboration Format
- BIM: Building Information Modelling
- BPMN: Business Process Modelling Notation
- bSDD: buildingSMART Data Dictionary
- CB-NL: Concept Library the Netherlands
- CityGML: City Geography Markup Language
- CMO: Concept Modelling Ontology
- gbXML: green building XML
- GIS: Geographic Information System
- GML: Geography Markup Language
- HTTP: Hypertext Transfer Protocol
- IDM: Information Delivery Manual
- IFC: Industry Foundation Classes
- IFD (1): International Framework for Dictionaries
- IFD (2): Industrial, Flexible and Demountable Building (Dutch standards)
- JSON: JavaScript Object Notation
- LOD (1): Linked Open Data (well-known in the semantic web community);
- LOD (2): Level of Detail/Development (used in the AEC industry)
- MVD: Model View Definition
- OGC: Open Geospatial Consortium
- OWL: Web Ontology Language
- REAP: Rotterdam Energy Approach and Planning
- RIF: Rule Interchange Format
- PoR: Programme of Requirements
- RDF: Resource Description Framework
- SKOS: Simple Knowledge Organization System
- SPARQL: SPARQL Protocol And RDF Query Language
- STEP: Standard for the Exchange of Product Model Data
- SW: Semantic Web
- SWRL: Semantic Web Rule Language
- Turtle: Terse RDF Triple Language
- URI/URL: Uniform Resource Identify/Locator
- W3C: World Wide Web Consortium
- XML: eXtensible Markup Language
- XSD: XML Schema Definition

Definitions

The following definitions explain specific technical terms used in ontology research.

Ontology: An ontology is an abstract, simplified view of a part of reality to be represented for some purpose. An ontology is essentially a set of concepts, properties and relationships. Furthermore, it contains data types and all kinds of restrictions (cardinality restrictions, universal / existential logical restrictions, value restrictions, and other constraints). Or, an ontology represents knowledge as a set of concepts within a domain, using a shared vocabulary to denote the types, properties and interrelationships of those concepts. (Wikipedia[1])

Hierarchy: A hierarchy is a set of classes or properties connected by a specific object property that constitutes a partial or complete order between those classes. Such object property can be used to say that one class is 'higher/lower' than another class. Note: a hierarchy is not necessarily having a tree-structure: one higher class might be associated to 0, 1 or more 'lower' classes and one lower class might be associated to 0, 1, or more 'higher' classes. Often the interest goes to a hierarchy that constitutes a complete order: all classes of an ontology are part of the hierarchy, there are no "hanging classes", classes which have no higher/lower link with other classes. A hierarchy is often used to define common characteristics of several 'lower' classes at a common 'higher' class, such characteristics are said to be inherited downwards.

Taxonomy: A taxonomy is a special kind of hierarchy where the object property connecting the classes is a subclass/superclass relation with a top-level class (the predefined 'most generic' class). Another hierarchy example is a meronomy where the object property connecting the classes is a typical part. In general the focus will be in the first place on taxonomies but meronomies are made possible via restrictions where all, in some way restricted properties, are interpreted as "typical", where typical doesn't say anything about necessity. It is handy to make this (optional) relevance explicit so that the end-user can be provided with a template involving typical/relevant parts for an individual of certain class, rather than always assuming that 'anything can be a part of anything else'. A taxonomy or meronomy or both typically form(s) the "backbone" of an ontology.

Decomposition: A decomposition represents a whole-part relation, such as an assembly structure. Explicit decomposition can be applied on individual level by providing a predefined object property denoting the "has part" nature of the relationship on class-level. As stated before, typical decomposition will be handled via qualified restrictions on this "has part" object property.

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[1] http://en.wikipedia.org/wiki/Ontology_%28information_science%29 (accessed: 2014-01-20)

Contents

1. Introduction

1.1 Goals

The goals of this task 5.1 has been defined (1) To build a knowledge base on ontology work in the domain, and present a robust framework for the practical implementation by the design team, stakeholders, building occupants; (2) To use this knowledge base to develop an ontology-based energy information system and associated tools for design energy-efficient buildings and districts, which will lead to ontology enabled interoperability; and thus, (3) To proof the eligibility of ontologies in the preliminary design stage of both new and retrofitted buildings.

The use of ontology as a shared conceptualisation has the potential to represent and manage information. Ontologies formalize and represent information that is valuable to the end-users. Ontologies formalise concepts by setting a common vocabulary or a set of rules. They allow users to map the domain concepts to a computable format and to base their business information on the formalisation of concepts as a reference.

Ontologies always constitute the basic elements as formalized representations (ontological commitment), above which constraints can be expressed and rules can be executed. For the state of the art review presented in this deliverable two main questions are to be answered:

1. What kind of shared conceptualization or ontological commitments already exists and what is the technological basis for its specification?
2. What are the intended use cases? On that basis, it then becomes important to identify what kind of knowledge is needed (and must be captured) in order to support Streamer use cases.

1.2 Vision

Ontology is understood as:

- *Ontologies are the structural frameworks for organizing information and are used […] as a form of knowledge representation about the world or some part of it.* (Wikipedia[2])

As Streamer looks into research in accordance with practical needs, the interest in ontologies is driven by the domain ontology, i.e. the need for conceptualizing, organizing, and stating knowledge that is essential to energy-efficient hospital design using modern BIM and GIS technologies. Abstract philosophical and upper ontologies are therefore out of scope.

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[2] http://en.wikipedia.org/wiki/Ontology_%28information_science%29 (accessed: 2014-01-20)

1.3 Problem Statement

BIM, is now mainly understood as a methodology to design, construct and maintain facilities using shared information assets with latest software tools and services in a more collaborative environment.

A commonly accepted definition is:

- *Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder.* (NBIMS[3]).

The “shared knowledge resource for information about a facility” and in particular the “shared knowledge resource about energy-efficient hospitals” will therefore set the maximum boundaries for developing and using ontologies in Streamer. It is, however, still a very comprehensive and large boundary. Thus, the overall focus still needs to be limited.

One particular aspect of applying BIM is to focus on the “I” in B”I”M - the **information**. BIM is essentially **information management** for construction and operation projects. Information has to be managed through the whole life-cycle. In that life-cycle the same piece of information (e.g. the thermal performance of the facade or the total u-value of the roof plate, etc.) is often created several times independently by several participants using their own software tools. Confusion arises not only by re-entering of the values (where also the errors occur here), but also by different naming conventions or by different degrees of certainty of the provided values.

The management of the information thereby need to include:

1. *Stating the information requirement specific to either a life-cycle phase, or to a particular task* (what has to be delivered, by whom, when and in which level of detail or certainty),
2. *Creating the information* (when creating the information as property for a model element in a BIM authoring tool, which template is used, how is it named, does it comply with the information requirement),
3. *Comparing the information* (e.g. compare the “as required” room areas within the space program with the “as designed” area values of the design alternatives created by the designer),
4. *Validating the information deliveries* (e.g. make an automatic completeness check, that the BIM data within the virtual building model deliver by the architect or engineer has all required properties with values within an acceptable value range),
5. *Quality checks as extended validation services* (e.g. checking against building code or other design and engineering rules),
6. *Exchanging the rich information models between project participants in open standards* (such as IFC and CityGML) to prevent re-entering of information.

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[3] National BIM Standard – United States. National Building Information Model Standard Project Committee, http://www.nationalbimstandard.org/faq.php#faq1 (accessed: 2014-01-20)

These problem statements lead to the following challenges that can be expressed by research questions.

1.4 Challenges

Potential user related questions need to be answered:

- What are the benefits to hospital clients, if BIM / GIS with proper information management is used in new design and retrofitting of hospitals?
- Is there a common understanding among hospital clients, designers and contractors about the purpose and need for BIM information requirement management?
- To those that have heard / have experiences with system engineering – how does it relate to it?
- Is it ‘Level of Detail’, or ‘Level of Development’, or ‘Level of Definition’, or how are BIM information requirements stated and communicated between hospital clients and designers or contractors?
- Why are current techniques to develop BIM guidelines insufficient – or is this deemed to be sufficient if stated using conventional spreadsheets (as in Excel)?

Potential technology related questions need to be answered:

- Can semantic web technology and languages, such as OWL, be efficiently used to support BIM based information management, are those technologies robust enough, can it be proven to be realistic in time and budget?
- Can existing solutions and techniques, such as the IFC and cityGML, be integrated with results from ontology works (in particular semantic web technologies) without reinventing the wheel?
- Can emerging technologies to formalize BIM data delivery and validation, such as mvdXML, be used and enhanced, and how could it benefit from semantic web technologies?
- Can software templates, as used in BIM authoring tools (such as Revit families, Bentley cells, ArchiCAD GDL objects) be integrated into such a solution to ease the use in commercial environments,
- Can BIM validation and rule checking be enhanced? How does it perform compared with existing solutions, such as Solibri Model Checker, BIMserver.org, etc.? Can those tools be enhanced and integrated into such a solution?

1.5 Followed Approach

The development plan for T5.1 include (see Figure 1):

- Analysis of the state-of-the-art in ontological research and neighbourhood developments (information modelling and standardization, rule-based assistance and validation),
- Setting real-life end-user scenarios for applying such ontologies to energy-efficient hospital design and retrofitting,
- Defining the specification for applying / enhancing existing open standardization frameworks IFC and CityGML to satisfy the end-user scenarios by utilizing results from the ontology work
- Implementing a prototype to validate the approach and to be used within the Streamer demonstrators

The deliverable D5.1 covers the state of the art analysis and the identification of relevant end user scenarios and recommends specifications and existing early prototypes. The future deliverable D5.2 on “Semantic Web based

PMO (Product Modelling Ontology)" will focus on the chosen specifications and the actual prototyping of solutions. The Figure 1 shows the relationships.

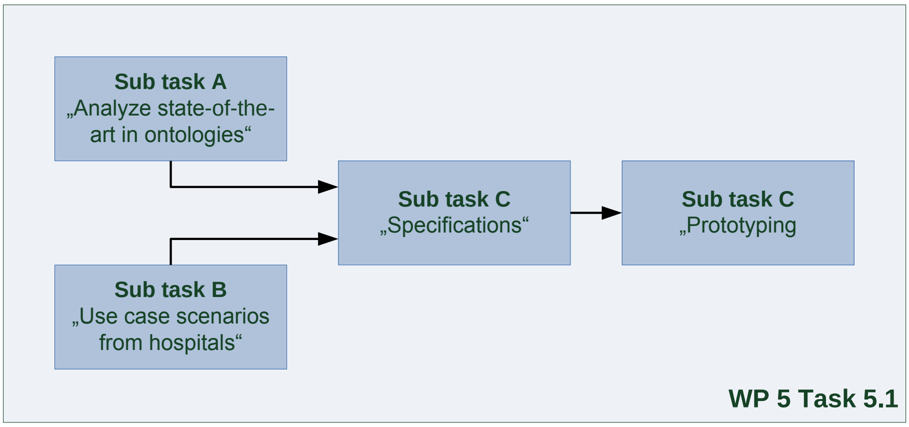

Figure 1: Structure of T5.1 (cross-links to other tasks and work packages are not shown)

The two sub tasks that are in scope of this deliverable include:

Subtask A: Analyse state-of-the-art in ontology works

From an IT specialist point of view:

- Research of ontological frameworks and applications that could be used by practical applications.
- Research how existing modelling frameworks and used-in-industry standards IFC and CityGML are capable to deliver the required information, and how to enhance the frameworks to also capture rules for information comparison, validation and deeper quality checks.
- Research on existing tools and solutions for information management, in particular tools that are in use by Streamer partners and are capable to handle open standards.

Subtask B: Identify use case scenarios

From a hospital client point of view:

- What is a typical use case scenario for stating information requirements (as in a room program), demanding it as part of a contractual delivery, and for checking and accepting the deliveries?
- What experience do the hospital clients have with BIM altogether, if at all?

From a designer point of view:

- What is a typical use case scenario for a designer to create / use a design template with the property configuration in order to create the demanded information?
- What is a typical use case scenario for a designer to extract schedules of information, or to self-check BIM deliverables prior to handing it over to the client, authorities, or project partners?
- What is a typical use case scenario for a designer to handle the different levels of development, not only for the geometric representations, but also for the attached information (properties)?

From a contractor point of view:

- What is the typical use case scenario to receive and validate BIM data from a designer for bidding or a part of a design-build or IPD contractual arrangement?

- What is a typical use case scenario for a contractor to create / use a design template with the property configuration in order to create the demanded information?

1.6 Organisation of the Deliverable

The Chapter 1 (the current one for the reader) introduces the purpose of this deliverable within Streamer context and provides a basic understanding of the main objectives, including the research questions that shall be answered.

The Chapters 2 corresponds to the sub task A and it provides results of the review of ontologies in the area of BIM and GIS. The Chapter 3 describe results from sub task B and it identifies use case scenarios for hospital design, whereas already following the IDM/MVD methodology presented in chapter 2.

The Chapter 4 summarizes the future research directions that are identified in Chapter 2 and 3. It provides a first summary and discusses the relevance of ontologies within Streamer. It also describes first prototype developments carried out within our feasibility studies. Finally the conclusions and recommendations for future work, predominately for the next deliverable D5.2 on “Semantic Web based PMO (Product Modelling Ontology)” but also in other work packages of Streamer, are presented in Chapter 5.

2. State-of-the-art in ontologies and BIM/GIS

Three areas will be discussed in this chapter for a state-of-the-art review related to ontological commitments and advanced information management, which is used in the highly fragmented, heterogeneous AEC. The following questions characterize these areas as follows:

- *How to represent buildings and their functional units as a part of reality that we wish to represent for some purpose?*

  The focus here is on accepted standards being the basis for data exchange use cases and especially to realize the BIM approach (machine to machine communication) but also to support communication in a more general context (machine to human and vice versa).
- *How to improve the process for finding, sharing and detailing design solutions; what is a reasonable sequence of activities; how to collaborate and how to share information?*

  These questions relate to commitments on how buildings are designed, built, maintained and refurbished.
- *What tool support exists in order to make use of the specifications in scope?*

  This is a more practical question and relates to solutions not only for using but also for managing and maintaining relevant specifications, which naturally will evolve over time and therefore needs to be continually adjusted and extended.

The focus of the subsequent sub chapters is both (1) on important technologies as well as (2) on relevant specifications for energy efficient buildings. But they do not go into details about the content. This is discussed in deliverable D6.5 with focus on data structures and energy related content.

2.1 Technologies and specifications used for ontologies

Ontologies capture the structure of a domain. So far, the main use case is on data exchange and, based on BIM and new linked data approaches, on data sharing. Substantial work has already been done in the past two decades in order to agree on data structures that provide the basis for machine to machine communication (i.e. reuse of data by another software system).

However, specification work on most of the “ontological commitments”[4] has been started before OWL became an ontology language standard. Therefore, such ontological structures are typically based on other “ontology” languages like XML schema or the EXPRESS data definition language (ISO 10303-11) that can be transferred to an OWL representation in order to benefit from this new technology and existing tools, and may to extend captured knowledge. The motivation to transfer it to OWL has to be driven by the use cases, as each of the languages have advantages and disadvantages for particular usages.

While the deliverable D6.5 is discussing the content and the use of such data exchange structures in context of Streamer, this review focusses on the following technologies and approaches based on the three aspects relevant to ontologies:

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[4] The term “ontological commitment” here refers to the main challenge that is to agree on a conceptualization, i.e. to define the scope, identify main elements, their attributes and relationships (including a taxonomy) and function.

- the kind of information or knowledge, that is included or missing, and how it is structured or can be extended through existing open specifications, such as IFC, gbXML, and CityGML,
- machine to human communication and the definition of general knowledge bases through dictionaries and common concept libraries, such as CB-NL, and bSDD approaches,
- enriched knowledge representation like parametric modelling and more flexible federated (web-enabled) data sources are discussed through Linked Data, CMO approaches

2.1.1 W3C Semantic Web Technologies and the Linked (open) Data approach

In addition to the classic "Web of documents" the World Wide Web Consortium (W3C) is helping to build a technology stack to support a "Web of data", the sort of data that is found in databases. The ultimate goal of the Web of data is to enable computers to do more useful work and to develop systems that can support trusted interactions over the network. The term "Semantic Web" refers to W3C's vision of the Web of linked data. Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data. Linked data are empowered by technologies/languages such as RDF, RDFS and OWL.

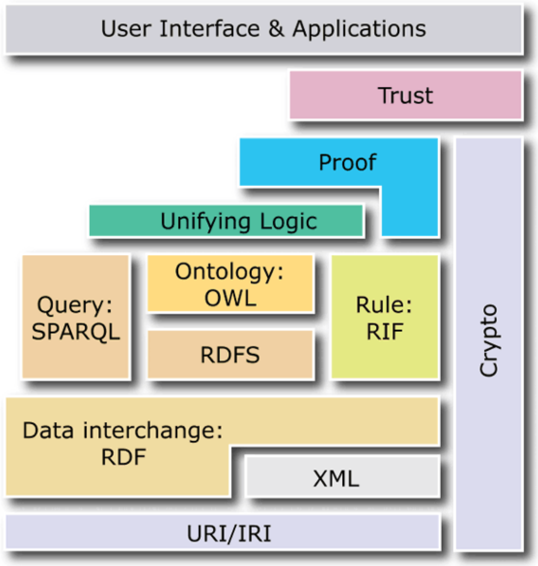

Figure 2: Semantic Web Stack of standards

The hierarchy of these languages is illustrated via the so called Semantic Web Stack which is shown in Figure 2.

- *RDF (Resource Description Framework)* is a general-purpose language for representing information in the Web. RDF data and its successors (RDFS and OWL) can be stored in a triple store and queried via SPARQL.
- *RDFS (Resource Description Framework Schema)* is a set of classes with certain properties using the RDF extensible knowledge representation language, providing basic elements for the description of ontologies, otherwise called RDF vocabularies, intended to structure RDF resources.
- *OWL (Web Ontology Language)* is similar to RDF and RDFS designed for use by applications that need to process the content of information instead of just presenting information to humans. OWL however facilitates greater machine interpretability of Web content than that supported by RDF and RDFS by providing additional vocabulary along with a formal semantics.

- *SPARQL (SPARQL Protocol and RDF Query Language)* is a semantic query language for databases, able to retrieve and manipulate data stored in RDF format.

The Linked (Open) Data concept is defined by the World Wide Web Consortium (W3C) and implies the following levels (see Figure 3):

1. Data is available for free on the web
2. It is machine-readable structured (i.e. not pdf)
3. In a non-proprietary format like XML (i.e. not Excel)
4. In “semantic web” formats (like RDF/XML, Turtle or JSON-LD) reusing semantic web language semantics (RDF, RDFS or OWL)
5. Linked to other data obtaining a kind of fully distributed web-based database

Figure 3 - Linked (Open) Data Requirements (Tim Berners-Lee, 2006)

“Data” can be divided in factual data sets (“content”) and conceptual data referred to as “ontologies” that denote concepts and their interrelationships by defining classes, datatype properties (“attributes”), object properties (“relationships”), data types and all kinds of restrictions. The standards involved are very well designed (have a sound mathematical/logic fundament) and have a lot of modelling power. The “traditional” web features are used where possible (such as the use of URL’s as identification mechanism).

Anyone can make its own data sets and ontologies in his own “name space” supporting multiple views/aspects/disciplines etc. where all this data can be flexibly linked together and dynamically updated in an “Open World” fashion. Because of the standard and equivalent syntax forms all this data can be imported/exported (uploaded/downloaded) or directly accessed via the standard SPARQL query language [SPARQL]. Meta-level access (info containers with linked data and possible non-linked data attached) is recently standardized the Linked Data Protocol [LDP]. More REST-like web services interfaces (for the actual data) for direct access of HTTP are underway. Because of its logic underpinnings logical inferences can be made and consistency can be checked by a variety of reasoners automatically.

2.1.2 **Industry Foundation Classes**

The Industry Foundation Classes (IFC) data structure can be seen as an essential part of a BIM solution approach. It marks the difference between BIM and BIM using non-proprietary, and therefore open, formats, or between BIM and open BIM.

The IFC specification is an open, international standard that enables neutral exchange and management of BIM data. It is developed and owned by a non-for-profit, non-governmental and open association, buildingSMART International, and final versions of the IFC specification are handed over to the International Standardization Organization (ISO) for recognition as an international standard.

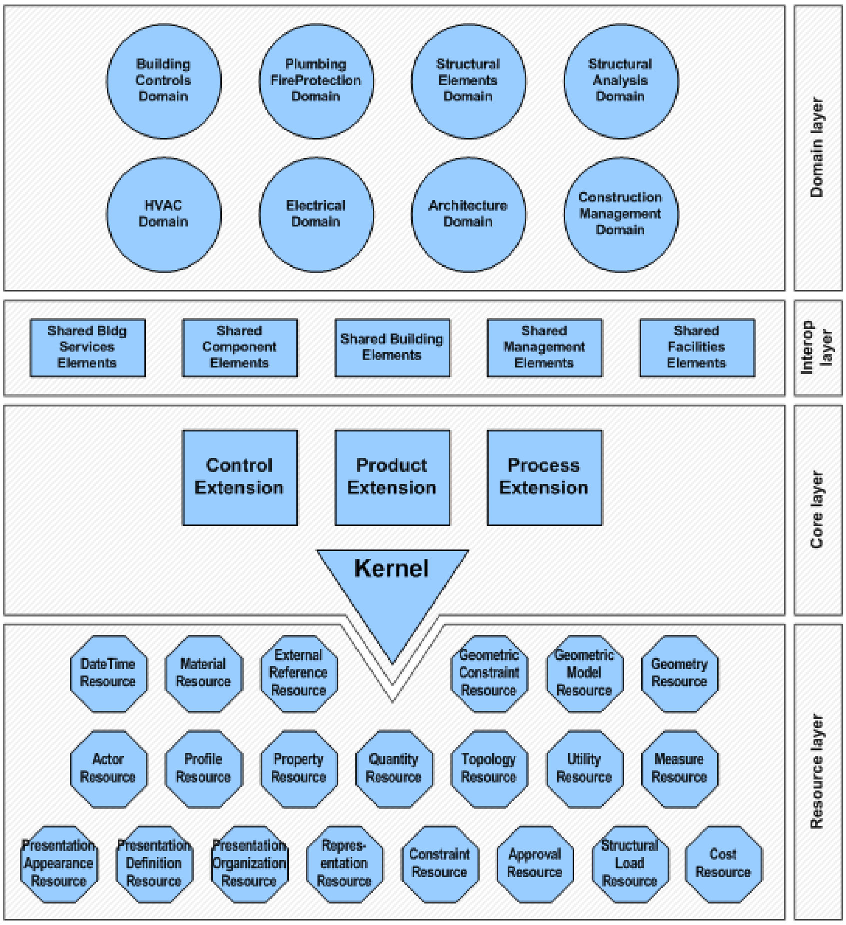

Figure 4: Layered architecture of the IFC standard (by buildingSMART)

IFC development started in 1996 and is influenced by many research projects related to object oriented product modelling and knowledge representation. The reference data structure is specified using the EXPRESS modelling language, which is based on the Extended Entity Relationship model (EER) and embedded in a family of ISO standards (ISO 10303). IFC does not make use of all features provided by EXPRESS for instance multiple inheritance or redefinition of attributes in order to simplify implementation[5]. Also, a set of modelling guidelines have

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[5] The IFC data structure is used as an import and export interface and thus is typically translated to or from an internal model of the application. Due to not fully compatible models data loss cannot be avoided in the translation processes.

been defined like the model layers and the ladder principle or the use of objectified relationships that shall reduce dependencies within the data structure and thus shall lead to a more easily decomposable data structure (see Figure 4).

Besides, EXPRESS offers a set of powerful features for specifying the consistency of provided data. It includes for instance differentiation between mandatory or optional attributes, definition of the cardinality, inverse relationships or the uniqueness of values. Such basic constraints are quite common in the IFC data structure. More complex constraints based on rules and functions are used too, but are limited to fundamental definitions. A general challenge of ensuring consistency and completeness of building data is that it typically depends on the use cases. For instance, thermal material properties are mandatory for energy analysis while they are not relevant in context of collision checking. Therefore, IFC does not include such kinds of context dependent restrictions as this has to be handled by additional process related specifications that are discussed in chapter 2.2.

Furthermore, EXPRESS being used as the main specification language for IFC there are also definitions based on XSD and even OWL. Both, ifcXML as well as ifcOWL[6] are derived from the IFC-EXPRESS specification. The transformation is based on general agreements how to map from EXPRESS to XSD or EXPRESS to OWL respectively. There might be additional context-dependent configuration settings to reflect specific use case requirements, but it does not result in additional knowledge encoded in ifcXML or ifcOWL. Contrary, because XSD and OWL are lacking some features of EXPRESS, not all constraints of IFC can be included in those specifications. Thus, using ifcXML or ifcOWL mainly offers a new toolset and modelling paradigm (e.g. open versus closed world assumption in case of ifcOWL), which may require additional knowledge to benefit from those languages or toolset solutions. While ifcXML is officially published and maintained by buildingSMART, this still has to be done for ifcOWL. A major first step will be to agree on an EXPRESS to OWL mapping approach in order to a) preserve as much as possible agreements contained in the IFC-EXPRESS reference definition and b) agree on main use cases for ifcOWL (e.g. to support publication of IFC data using the Linked Open Data approach).

The ability of IFC to represent knowledge, aside from the specific instantiation of a facility involves several aspects of the schema. These aspects are intended to be re-usable from project to project.

- The Product and Process extensions (see the squares in Figure 4) include the ability to define product and process types, such as standard specifications of products and tasks.
- Performance tables or graphs can be associated to any object
- The resource layers (see the octagons in Figure 4) represent common background objects, such as materials (Material resource) and cost rates (Cost resource).
- The constraint resource allows the representation of lookup tables for object variants such as product types, relationships between attributes across several objects, and detailed Boolean trees of objectives and metrics, which can be abstract or can relate to objects

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[6] There are several approaches how to translate IFC-EXPRESS to ifcOWL. Different use cases for example data publication, interlinking or reasoning may require different mapping approaches. However, efforts are currently made to harmonize existing approaches and to provide a recommended, standardized ifcOWL representation that covers requirements of many use cases for ifcOWL. At the time of this writing a proposal is published at: http://www.w3.org/community/lbd/ifcowl/

Software applications with IFC support today are mainly based on the previous release IFC2x3 and typically support design coordination and Facility Management data handover. In those scenarios, IFC is used as neutral structure to share information while the knowledge to process and evaluate that information, the business logic, is hidden in the design tools.

IFC4 is the latest version and was released beginning of 2013. It has been accepted by ISO as an International Standard ISO 16739[7]. There are about 760 entity or class definitions, 390 data type definitions and 500 property and quantity set definitions. They cover all main building domains and supports many BIM-based use cases mainly in the area of building design and construction but also in facilities management. Based on IFC4 future extensions are prepared with the main focus of expanding the scope towards roads, rails, bridges and other infrastructure works. But other new areas are of interest a well, like a separate add-on sub-schema for parametric behaviour where a draft is already available. This supports mathematical, logical and string relationships between multiple object attributes, geometric constraints and relationships.

Today, IFC can be seen as a reference structure for BIM-based data exchange. It is a neutral and open ontological commitment that supports a wide spectrum of use cases. Meanwhile, it is supported by a number of software applications and people get more and more trained in using that technology.

2.1.3 buildingSMART Data Dictionary and International Framework for Dictionaries

The aim of the buildingSMART Data Dictionary (bsDD) is to "*manage and develop an open, international and multilingual dictionary"* for the building industry. It is based on the International Framework for Dictionaries[8] (IFD), which *"specifies a language-independent information model which can be used for the development of dictionaries used to store or provide information about construction works. It enables classification systems, information models, object models and process models to be referenced from within a common framework."*

Thus, while IFD can be seen as a knowledge representation format, bsDD is about the content for the building industry. bsDD defines a set of concepts like wall, window, space or building storey describing physical or virtual artefacts about the building or related activities. Those concepts are usually characterized by the following information types:

- Unique identification, which enables to distinguish a concept from other concepts
- Name of the concept, typically including synonyms and translations to other languages
- Description, which defines a concept; typically provided in different languages
- Specialization and generalisation relationship showing what concepts are more special or more general
- Composition/decomposition relationship showing what concepts are part of another concept
- Properties that further characterize a concept
- Link to classifications

Based on the IFD approach and the content provided by bsDD, a main use case is to act as an information hub that integrates different views on a building. Figure 5 shows the principle of this context-dependent view ap-

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[7] See http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=51622 (accessed 06.02.2015)

[8] ISO 12006-3, 2007 - Organization of information about construction works -- Part 3: Framework for object-oriented information

proach. It shows the concept of a window and a set of related properties that are partially relevant in different contexts like a briefing document, a specific classification system or in a CAD system. Due to the multi-lingual approach, it also enables to map between classifications and to translate to other languages or data structures.

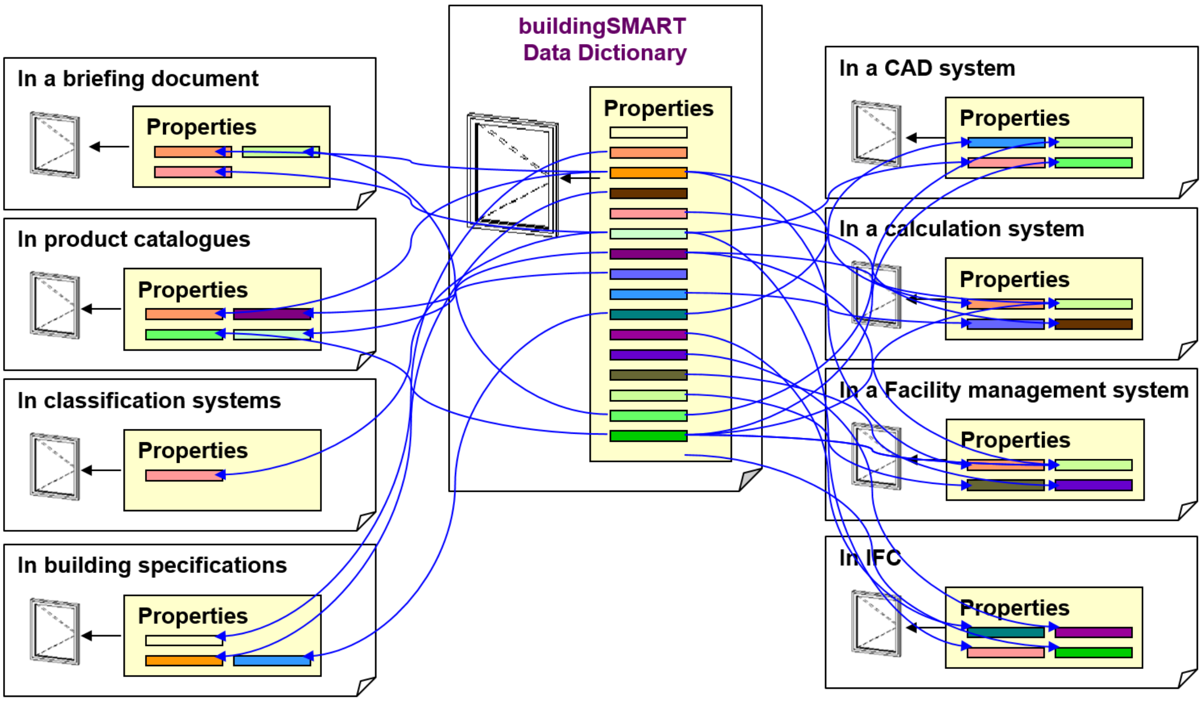

Figure 5: Principle of bsDD showing relevant properties of a window in different contexts (by buildingSMART).

A main challenge of bsDD is to add and manage required content. For this, bsDD partially relies on available specifications like the classification systems Omniclass[9] and Uniclass[10] or the property set definitions from the IFC4 data structure. Those specifications provide a reference structure for further content, which is currently mainly coming from buildingSMART Norway and the Dutch LexiCon.

The bsDD can be accessed through an API, which is documented at http://bsdd.buildingsmart.org/docs/. Also, a web interface is available at http://bsdd.buildingsmart.org/#concept/search that enables to browse through available content. At the time of this writing coverage of main concepts seems to be quite acceptable, mostly including translation to other languages. But a lot of more specialized concepts are still missing.

2.1.4 Concepten Bibliotheek Nederland

The aim of Concept Library the Netherlands (CB-NL) is make an unambiguous description of built environment concepts as similar to bsDD. The difference is mainly in the underlying standards, where bsDD uses IFD (ISO 12006-3) and CB-NL semantic web technology. Similar to bsDD, CB-NL does not only include concepts to describe physical objects, such as a door, a roof or a window, but also concepts to describe spatial objects, such as a meeting room, a parking space or even a town. The contents of the CB-NL apply to the entire lifecycle of a

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[9] http://www.omniclass.org/
[10] http://www.cpic.org.uk/uniclass/

project and include all sub-sectors in construction, both residential and non-residential building (B&U). Its contents also apply to all groundwork, road and hydraulic engineering (GWW) as well as the spatial (geo-) environment.

The CB-NL will be a smart dictionary for the Dutch built environment, whose aim is to end current miscommunication. The naming used to identify object is still under discussion although it will likely be English, making it usable for other countries as well. It will be complex in design, but easy to use. In addition to that, it will be available free of charge through the Internet. The original plan was to have a first version before the end of 2014 but this is not achieved until the writings of this deliverable.

To build a workable concept library requires a lot of work. A CB-NL team has been formed for this purpose consisting of several staff members and working groups for both residential and non-residential building (B&U), groundwork, road and hydraulic engineering (GWW) and the spatial (geo-) environment. Their aim is to collect the most appropriate content for the CB-NL from within their specific fields. The ICT working group is also involved in developing the ICT architecture on which the CB-NL will be built, in modelling the content, and furthermore with its customisation with software suppliers and producers. The CB-NL is currently housed at Geonovum.

The CB-NL workgroup philosophy is to use several available classifications and other knowledge collections. These are from knowledge institutes, for example ETIM (European Technical Information Model), NEN (Netherlands Standard Institute), STABU (a group of large, cooperating companies positioned within the Dutch building industry) and CROW (a knowledge institute in the field of infrastructure, public space, traffic and transport). They will link all this information through the CB-NL, thereby ensuring uniformity in the descriptions. The CB-NL will, therefore, not be a new library but a binding element between the existing sources.

2.1.5 Concept Modelling Ontology

Concept Modelling Ontology (CMO) is a reusable, generic ontology (also referred to as an “upper ontology”) that enables full-power, pure semantic, concept modelling adding extra semantic modelling capabilities cleanly on top of the W3C OWL2 Recommendation. When needed, it can also add geometry mapping/derivation on top of W3C OWL2. CMO can therefore be seen as an additional layer in the Semantic web layer stack. CMO can be imported in all CMO/OWL2-compliant end-user ontologies. The design principles used during the development of CMO are intended to be used when modelling based on CMO as well. These design principles are:

- Maximize reuse of existing resources (OWL2, RDFS, RDF, SPARQL)
- Minimize own restrictions, extensions and modelling rules
- Keep everything as simple as possible (but not too simple)

Not all modelling techniques addressed in CMO will be valuable to each kind of modelling. Therefore, the CMO development group defined profiles (currently 2 are finalized and a third is still under development) for the CMO Modelling Guide. The profiles are:

> **Profile 1** – These are just guidelines for OWL2/RDFS/RDF and adding only new modelling primitives on class level (for use on the individual level). This profile guarantees maximal reuse and OWL2/RDFS/RDF complian-

cy without any extra assumption on the language/meta-level. If you can live without the added Profile 2 modelling power this is the profile of preference! Profile 1 – capabilities on top of OWL2/RDFS/RDF

- explicit quantity and unit annotation modelling
- individual level decomposition modelling (typical decomposition via standard restrictions)

Profile 2 – Now Profile 1 is extended with a small set of extra primitives on meta-level to enhance modelling power (for use also on the class level). Since the language level itself is adapted, the “standard language”-aspect is compromised for more modelling power. Profile 2 – capabilities on top of Profile 1

- class level and individual level requirements modelling, some forms don’t need meta-level extension but we kept them together as requirement modelling capabilities in this profile 2

Profile 3 – This one is still under development and add geometry related aspects.

The set of extra modelling primitives for “Profile 1” and “Profile 2” are modelled as a generic ‘upper ontology’ cmo.ttl (http://www.modelservers.org/public/ontologies/cmo/cmo.ttl). This ontology can be imported and reused in/by any other ontology as long as it is OWL2 compliant. The prefix for CMO modelling primitives is: ”cmo”.

CMO is the joined work of the institutes and companies TNO, CSTB and RDF. Those are the owners of the specification that will adopt, develop and maintain it. CMO specification itself is open and free to use to anyone.

2.1.6 CityGML

The City Geography Markup Language (CityGML) is an open standard of the Open Geospatial Consortium for 3D city models [CityGML2012]. CityGML is based on XML and is an application for the Geography Markup Language (GML) version 3.1.1 [GML2004]. The model is subdivided into different modules, like building, bridge, tunnel, transportation, vegetation, terrain, water body and city furniture. In order to model city object on different scales, CityGML allows different Levels of Detail (LoD). The applied LoD concept refines not only the geometry of an object with a higher level of detail, but also increases the semantic richness.

As a general-purpose model, CityGML is not considering detailed requirements of a certain application area. Objects and properties, which are not part of the CityGML definition can be modelled by generic objects and attributes, or by extending the CityGML schema with an Application Domain Extension (ADE) (ADE2014). In contrast to generic objects and attributes, an ADE is formally specified as XML schema, which can be used to validate instant documents. Examples for such CityGML extensions are as the ADE for Noise Immission Simulation [CityGML2012] or the UtilityNetwork ADE (Becker2011).

Most available CityGML data sets are focusing on LoD1 or LoD2 buildings modelled. Landmarks sometimes are modelled in LoD3. LoD4 building are not available in a mentionable number. Data set using other modules, like transportation or vegetation, are available, but mostly not covering large areas.

The Centre Universitaire d’Informatique at the University of Geneva has translated the CityGML XML schema to OWL (schema see http://cui.unige.ch/isi/icle-wiki/ontologies).

2.1.7 gbXML

The green building extensible mark-up language (gbXML) is an open, non-proprietary information model that was developed by a non-profit organisation (also called gb.XML.org) to facilitate intelligent information exchange, enabling integrated interoperability between building design models and a variety of engineering analysis tools. The first version of the gbXML was launched on June of 2000 and the latest version of the model when writing this document is now V5.12 that has been released in August 2014. It is worth mentioning that this schema is maintained and followed by different software editors mainly in the U.S (Carmel Software, Bentley, Autodesk DOE, EDSLTa, etc.).

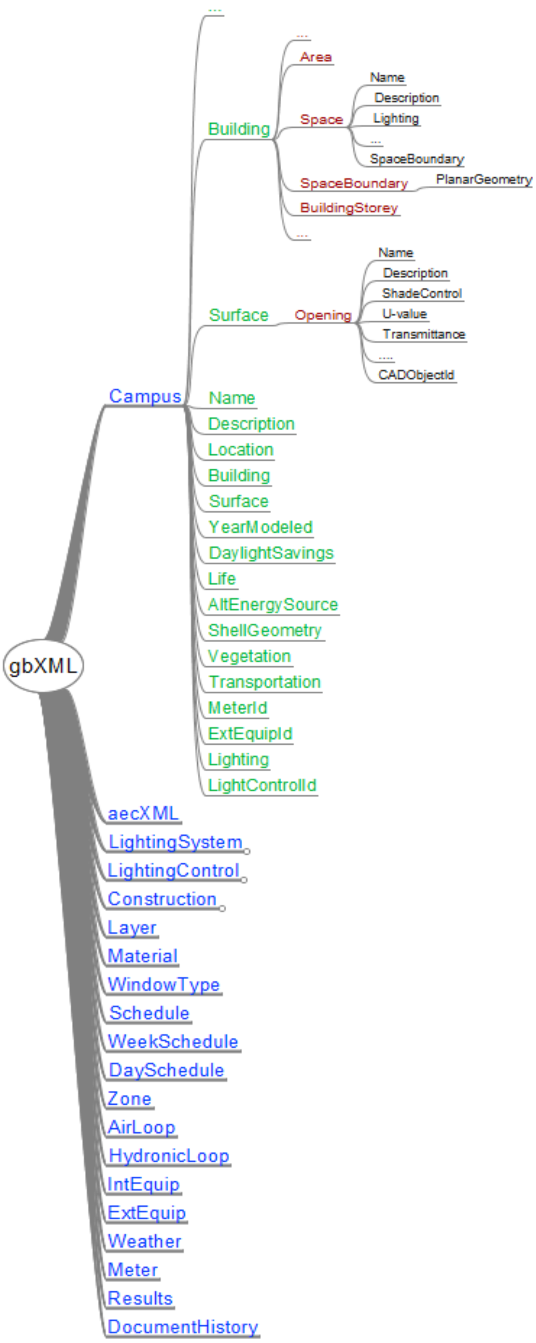

Figure 6: Partial representation of the gbXML tree of element.

The application of gbXML is mainly focusing on the energy simulation domain. Since the beginning, it has been designed to keep a privileged link with the BIM. There is a dedicated attribute named “ifcGUID” that maintains consistency between IFC and gbXML. The gbXML schema could be seen as a pragmatic schema resulting from a bottom-up approach, well linked with IFC and well supported also by many simulation software.

All the gbXML elements are organised in a tree starting from the “gbXML” element itself. There are more than 300 elements in the current version (5.12) and more than one hundred enumeration types. Under the root “gbXML, the “Campus” element is the starting one. It should be used as the base for all physical objects. According to the model, a “Campus” may contain one or more “Building”(s). The “Building” contains among various elements the notion of “Space” which is in itself defined as a volume enclosed by surfaces. Different elements are then used to identify the boundaries of the volume (“SpaceBoundary”; “PlanarGeometry”; “ShellGeometry”; “ClosedShell”; …).

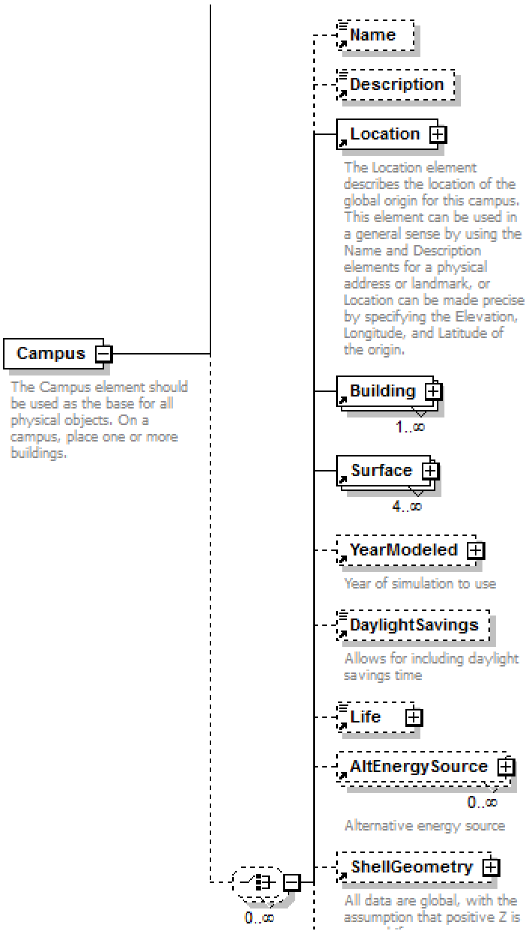

Figure 7: Example of cardinality constraints on the gbXML Elements

In order to generate a proper gbXML file, it is mandatory to define this decomposition of a building into spaces and to define is these spaces have internal/external surfaces and how they are linked together (which part are in common). There are other requirements expressed in the gbXML model. Each element comes with a set of attributes and these attributes may be marked as “Required”. On the same hand, the cardinality of the elements is defined in the model (see the figure below). For instance, in the example above, it is formally said that: If a “Campus” contains at least one “Building” there must be also four “Surface” elements, one “Location” element defined.

2.2 Information Management and collaboration support

While the focus of the previous chapter was on knowledge about the building and related domains, this chapter is dedicated to knowledge about design and maintenance processes. A main challenge especially in building design but also in later lifecycle phases is to coordinate activities and to provide the right information, in the right data format to the right person (or tools). Not all information is required or available at a particular point in time. Therefore, information management becomes a crucial topic on top of the ontological commitments presented in chapter 2.1. This chapter reviews approaches to capture process knowledge that is required to manage building information (see IDM and MVD), to agree how to describe and review design changes (BCF) or to automate model checking (Data validation). Additionally, it shortly reviews approaches for mapping, transformation and linking of data. Thus, the following sub chapters describe ontological commitments that provide the basis for information management and collaboration support. They will be used in specification of the required knowledge for selected Streamer use cases for chapter 3.

2.2.1 Information Delivery Manuals

Process modelling is a key method to improve efficiency and quality in all kinds of industry. However, it is not yet common in the building industry due to its highly creative character with dynamic processes and the one of the kind products with own constraints and requirements. Each building project is different in many aspects. Normally there are different team members, responsibilities and last not least tools from a heterogeneous software landscape. This makes it extremely difficult to standardize processes and to specify data exchange.

The Information Delivery Manual method (IDM), also ISO 29481-1[11], was developed by buildingSMART to deal with this challenge. It adapts proven solutions like the Business Process Modelling Notation (BPMN) and defines a modular, step-by-step method to capture business requirements and to translate them to a technical solution. The overall process is shown in Figure 8. There two main parts: (I) processes and exchange requirements defined by domain experts and (II) related IT specifications developed by modelling and software experts. Each of those parts is divided into different steps focussing on a specific result that (a) is input for subsequent steps and (b) can be reused and adjusted in other contexts or projects. While the first part is known as IDM and is discussed in this section, the second part is known as MVD (Model View Definition) and discussed in the next sub chapter. It is important to highlight the aims of the IDM/MVD methodology, which is not only to develop an IT-solution for a specific business case but also (1) to document and publish the developed solution so that it can be understood and used by others and (2) to provide specifications that can reused and adjusted to specific needs.

IDM's aim is to offer standardized methods to answer the following questions:

- Who needs the information extracted from the building information model?
- At which point in time this information is needed?
- Which minimal amount of data has to be exchanged?

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[11] *ISO 29481-1:2010 "Building information modelling -- Information delivery manual -- Part 1: Methodology and format"*

The essential parts of an Information Delivery Manual are:

- Defining "who" and "when" by means of a general process map using the Business Process Modelling Notation (BPMN) + additional descriptive text (example see chapter 3.1).
- Defining "what", thus the required data as exchange requirements listed in a semi-formal tabular form (see also 2.3.4).

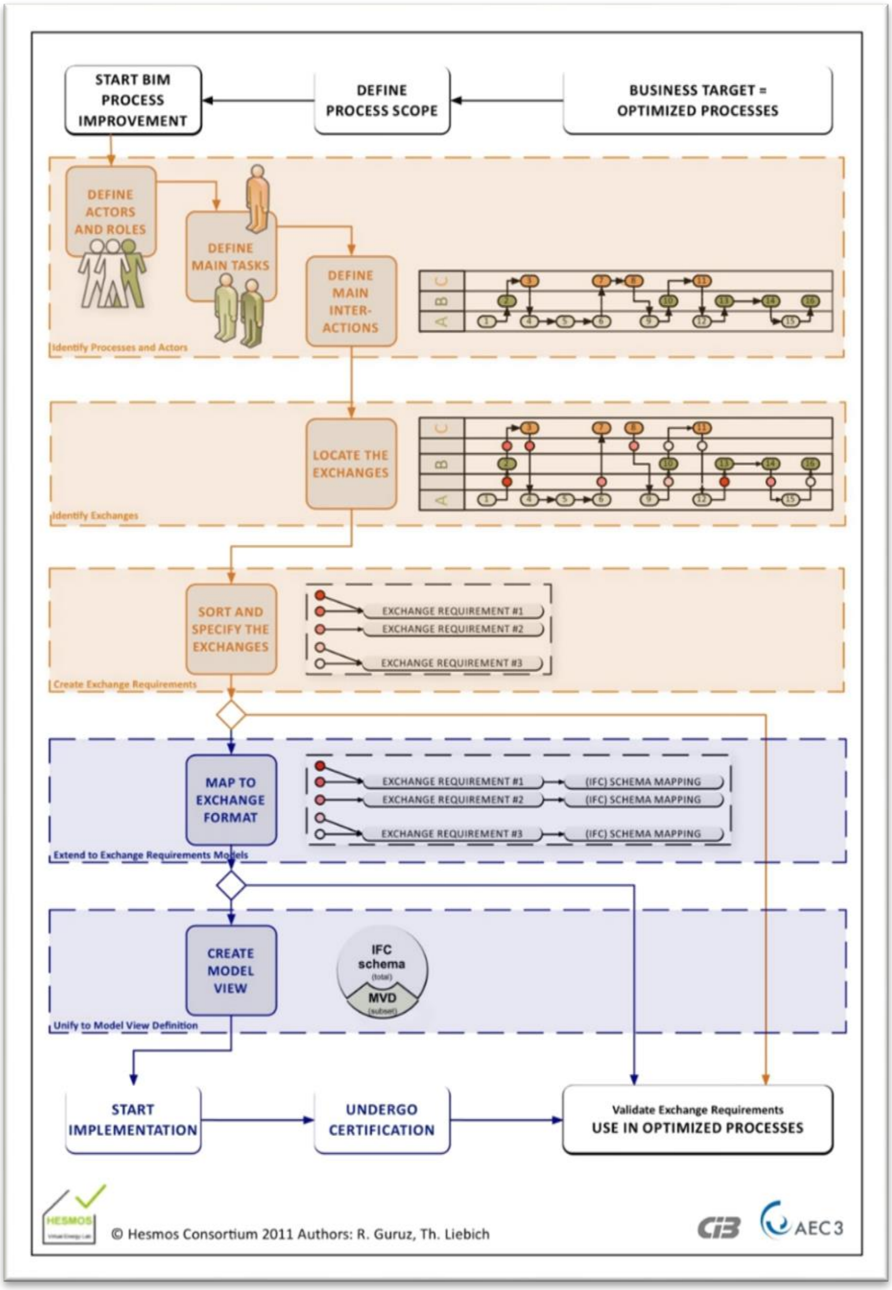

Figure 8: Overview of the IDM (orange) and MVD (blue) methodology developed by buildingSMART (Liebich et al. 2011).

The IDM standard itself only describes the method how such a manual for the information exchange can be produced. The result will be a specific manual or arrangement for a specific process: e.g. hospital design in early design. It reflects the view of domain experts described in a semi-formal definition, which

- improves communication between domain experts, and
- has to be translated into a technical specification, e.g. a data structure like IFC in order to be clear about how to implement business requirements

The definition of an IDM has much in common with knowledge acquisition. Although there are couple of improvement in recent years, this methodology is only partially supported by adequate tools, in particular the documentation and management of so called Exchange Requirements is not yet properly supported (see chapter 2.3.4).
Once an IDM has been produced, it is suggested that its use being summarised using ISO 12911 Framework for BIM guidelines. This summarises the outcome in terms of the strategic goal(s), for example ‘concept cost evaluation’), the management controls, for example automated checking of the MVD and classification of systems to an agreed table) and required inputs (for example, accurate use of layering codes).

Development of IDM’s is an ongoing effort. Various definitions are already published and available for download, for instance from the buildingSMART website[12]. It is expected that a lot of such definitions are necessary to specify building design activities and to reflect specific needs (e.g. for different types of buildings, to cover country-specific requirements etc.). Each IDM follows the same methodology and thus is a good basis to provide tool support, for example to manage and reuse requirements in a central database as discussed in chapter 4.3.1. Other agreements such as various BIM guidelines[13] or other recommendations like the Level of Developments[14] might be transformed to processes and exchange requirements according to the IDM methodology, which would further standardize and thus simplify communication about required data.

2.2.2 Model View Definitions

An IDM does not define the technology that can be used to exchange required information. For this purpose buildingSMART developed the Model View Definition approach (MVD). An MVD identifies a certain subset of the data exchange format that is to be used to deliver the required data. In case of the IFC standard a MVD identifies not only a subset of the data schema but also delivers representation and implementation requirements that are needed to implement software interfaces. Defining a new MVD is a comprehensive process performed by data model specialists.

From IFC4 onwards an MVD is defined using the mvdXML specification[15], which now allows to define a MVD is a unique, standardized and machine-readable way. An mvdXML specification can also be used for deriving filter definitions to extract the data relevant for the process or for the completeness and quality control when receiving the building information models. The model views therefore define how required information is mapped to the IFC data structure. Additionally, data requirements can be included that state which data exchange elements are obligatory or which range of values is applicable.

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[12] http://iug.buildingsmart.org/idms/information-delivery-manuals
[13] There are several BIM guidelines available that clarify collaborative use of BIM and expected data exchange.
[14] http://bimforum.org/lod/
[15] http://www.buildingsmart-tech.org/specifications/mvd-overview/mvd-overview-summary

While current mvdXML release 1.0 is focused on documentation purposes a couple of improvements are already discussed to enhance the basic data checking capabilities. The new proposal 1.1 will be a major step towards BIM data management features from which Streamer can benefit, provide further testing and proposals for further improvements.

Similar to IDM various MVDs are already available, for example on the buildingSMART website[16]. The main view for IFC-based data exchange is the Coordination View. Other views are defined for quantity take off, energy analysis, facilities management and structural analysis.

2.2.3 BIM Collaboration Format

In all phases of a building planning and construction process collaborating between various actors is essential. To support this, methods and data formats for a BIM-integrated communication are necessary. In this context, BIM-integrated means that all information being relevant for the collaboration can be assigned to a specific object in the building information model.

In order to achieve a widely use, which is essential for communication and collaboration, it must be easy for software applications to support the format. Furthermore, the communication itself should be based on web services.

In October 2014, buildingSMART released the second version of the BIM Collaboration Format (BCF) to support workflow communication in BIM processes [BCF2015]. The XML based format allows to exchange mark-ups, issues, proposals and change requests with a relation to the corresponding effected BIM object. Data exchanged via BCF include textual information, preferred viewpoints, snapshots and attachments (files or external references). A special case of such attachments is the exchange of small partial models between applications, the so-called “BIM-Snippet”.

A “BIM-Snippet” can be a text file with any kind of externally specified syntax. Regarding interoperability, the usage of “Simple-ifcXML” [Linhard 2015] is recommended. A typical application for using “BIM-Snippet” is the exchange of a “provision for void” (including geometry of the cut-out), send from the building service engineer to the architect and structural engineer. For exchanging messages via BCF, buildingSMART provides a BCF 2.0 RESTful API [BCF-API 2014]. This API allows using standardized web services including managing user right and roles.

BCF is an extension to BIM, in particular the open IFC format. While it addresses a very important functionality for collaborative design the complexity of the format itself is rather simple as it contains only few concept definitions that are needed for structured exchange of messages. However, through its connection to BIM data it becomes a very powerful specification that is discussed in more detail in the deliverable D6.5.

2.2.4 Data validation

The data validation could be understood in several ways. One is the validation of the various project models coming from different sources (Architectural model vs. Structural model). This kind of validation requires tools that

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[16] http://www.buildingsmart-tech.org/specifications/ifc-view-definition

could perform BIM to BIM comparison and analysis. This point is illustrated in a chapter 2.3.5 illustrating how a software solution such as Solibri Model Checker is executing the checks.

The current section deals with the issue of the validation of the construction/project model against external and heterogeneous sources of information like the various regulations that applies in the frame of a hospital. Nowadays, in the field of building engineering construction, Building Information Modelling (BIM) occupies a pivotal place for information management. In terms of knowledge representation itself, data are expressed using the IFC standard. Unfortunately, this 'language' is not suitable for some key tasks in the field. For instance, the IFC standard has shown its limits (i) for reusability of others domain knowledge, (ii) for information partitioning and (iii) for conformity checking.

As a data definition standard IFC was not designed to interact with various vocabularies and knowledge bases. Thus, when working with IFC data structures only, developers are limited to the knowledge already expressed in IFC. It means that the data standard itself cannot reuse for example a repository of material characteristics, or information about the geology or the history of a region, additional (and often proprietary) software solutions are needed to link that data. In addition, IFC itself is not suitable for rule checking and conformity with legal texts, software such as Solibri Model Checker would be needed using proprietary rule language to code rules. It would be beneficial to have such linked data and checking rules being formulated as part of an open standard as well.

One example is the development of mvdXML that can be used to restrict the data structures of IFC to the subset needed by the use case, and to add simple validation rules that can ensure that the IFC instance data submitted does have a sufficient level of information as required by the use case.

Tools and technologies developed in the Semantic Web (SW) community bring relevant solutions too, that would complement the data definitions provided by IFC. To enable these solutions the knowledge has to be represented using SW standards, especially RDF (Resource Description Framework), and ways of thinking: express facts using triples (<subject, predicate, object>). This constraint has led to approaches proposing a transformation or a translation of IFC schema from EXPRESS to OWL (Web Ontology Language). By adopting this OWL representation, the problems (i) and (ii) are resolved through the Linked Data principles: entities can be found through HTTP URIs using SW standards (mainly RDF and SPARQL – see chapter 2.1.1). Concerning the rule checking problem, SW proposes various solutions. The W3C proposes standards like SWRL (Semantic Web Rule Language), RIF (Rule Interchange Format) and N3Logic. All of these languages had been successfully used in the field of building engineering constructions. For instance, N3Logic had been used to express rules for acoustic performance checking, SWRL for defining new concepts (Farias et al. 2014).

In a more flexible and regulations-alike way, research in this field has proposed to represent regulations through a set of annotated SPARQL queries (Yurchyshyna et al. 2008). This method has the main advantage to make persistent a real bijection between legal texts and formal rules. Each query represents a given rule, and its annotations contain information about all the metadata about the document itself describing the rule, the precise domains linked to this requirement (accessibility, fire safety, energy, etc.), and the entities manipulated by the query (doors, lifts, parking, etc.). Moreover, all these queries are kept in a repository reachable through web services; consequently, using the various annotations, a rule checking process knows exactly which queries are suitable.

The application of the technologies mentioned above to practical challenges is still a research topic. Among the various challenges, there is the need to facilitate the natural language analysis to ease (automatize) the production of formal rules but also the question of the "formalise-ability" of the text remains a difficult topic. Yuchyshyna et a. (2008) illustrated that more than 30% of constraints expressed through 9 different regulatory texts about accessibility cannot be translated into formal rules.

2.2.5 Ontology Mapping and Transformation, Alignment

There is an immense amount of information produced constantly. This leads to a heterogeneous yet unmanageable set of data. And extracting any meaning becomes difficult. In order to tackle this issue, ontologies provided a first answer. They offer a model that structure and thus provide semantics to information.

The development of semantic models (ontologies) has been done in various sectors in order to address within a sector the semantic challenge (turning information into "knowledge"). But more and more, questions like the energy efficiency ask for holistic/global approaches that encompass various sectors. And the question of managing heterogeneity among various information resources is becoming more and more significant.

A main question for using ontologies is how to relate different existing ontologies together. This is called "the alignment of ontologies".

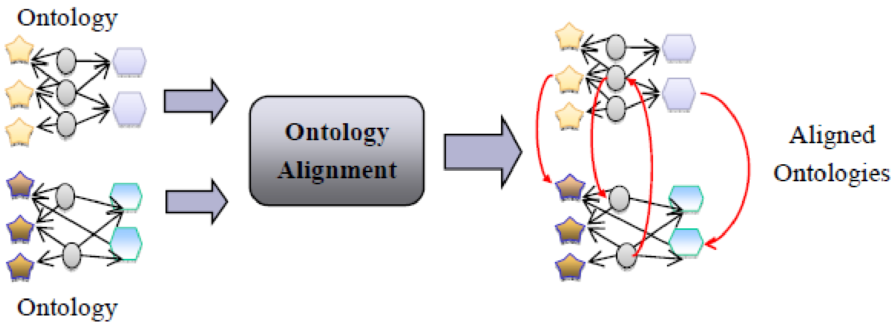
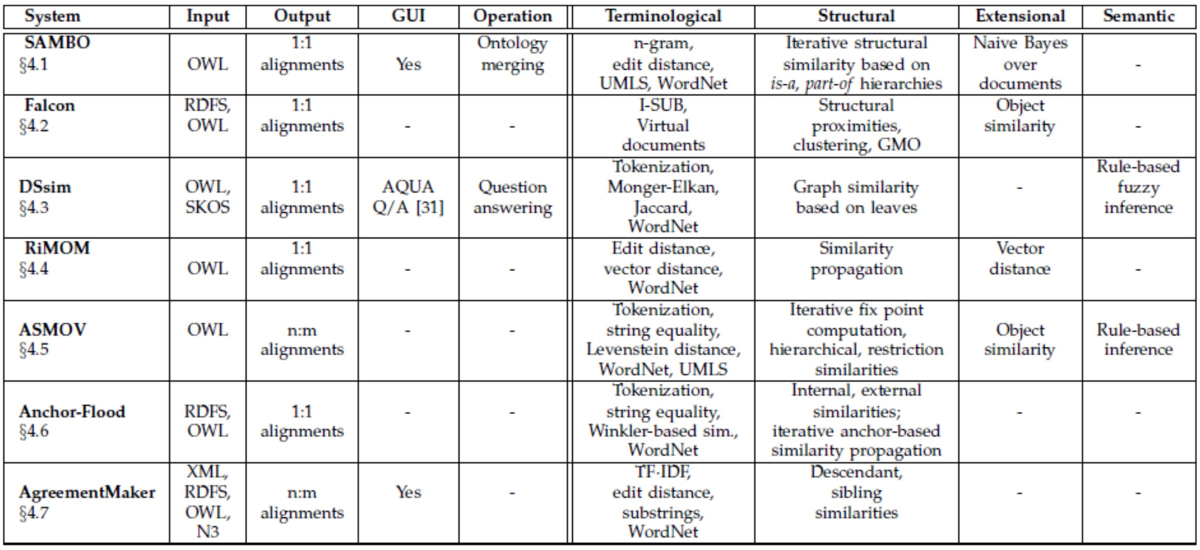


Figure 9: Alignment of two ontologies, mappings between related concepts, are shown in red. [Granitzer 2010].

The alignment approach involves analysing the different ontologies (data models) as structured sets of vocabularies and finding if there are similarities among them. Having then established bridges/equivalences between two ontologies, it is possible to translate (and keep the meaning of) instances (data) from one domain to another domain. But the nature itself of an alignment between two ontologies can have several facets. An alignment is a set of correspondences between entities belonging to the matched ontologies. Alignments can be of various cardinalities: 1:1 (one-to-one), 1:m (one-to-many), n:1 (many-to-one) or n:m (many-to-many). But also, the relation between the two classes/concepts could have several aspects. It could be either an equivalence (the two notions are equal), or one concept is more generic or more specialised than the other (and "which one is the most generic?”). How far the two considered concepts are from a semantic point of view?”) are notions that can be translated also by giving a value to the alignment of two considered concepts (Shvaiko et al. 2013).

As shown in the table below, there are todays various tools that support ontology matching.

Table 1: Analytical comparison of the recent matching systems [Shvaiko et al. 2013].



System	Input	Output	GUI	Operation	Terminological	Structural	Extensional	Semantic
SAMBO §4.1	OWL	1:1 alignments	Yes	Ontology merging	n-gram, edit distance, UMLS, WordNet	Iterative structural similarity based on *is-a*, *part-of* hierarchies	Naive Bayes over documents	-
Falcon §4.2	RDFS, OWL	1:1 alignments	-	-	I-SUB, Virtual documents	Structural proximities, clustering, GMO	Object similarity	-
DSsim §4.3	OWL, SKOS	1:1 alignments	AQUA Q/A [31]	Question answering	Tokenization, Monger-Elkan, Jaccard, WordNet	Graph similarity based on leaves	-	Rule-based fuzzy inference
RiMOM §4.4	OWL	1:1 alignments	-	-	Edit distance, vector distance, WordNet	Similarity propagation	Vector distance	-
ASMOV §4.5	OWL	n:m alignments	-	-	Tokenization, string equality, Levenstein distance, WordNet, UMLS	Iterative fix point computation, hierarchical, restriction similarities	Object similarity	Rule-based inference
Anchor-Flood §4.6	RDFS, OWL	1:1 alignments	-	-	Tokenization, string equality, Winkler-based sim., WordNet	Internal, external similarities; iterative anchor-based similarity propagation	-	-
AgreementMaker §4.7	XML, RDFS, OWL, N3	n:m alignments	Yes	-	TF-IDF, edit distance, substrings, WordNet	Descendant, sibling similarities	-	-

The main interest for Streamer could rely on the help that such technics could have in the elaboration of our own ontology by helping in the alignment of vocabularies.

2.3 Tools

While previous chapters describe technologies and specifications for capturing knowledge for Streamer use cases, this chapter describes applicable tools that enable to specify and manage that kind of knowledge. This is an equally important aspect because appropriate tools in terms of functionality (as well as their usability and affordability) is a crucial criterion for acceptance and use of new technologies.

Two main types of tools are discussed in this chapter: (1) tools that are needed to specify and maintain reusable domain knowledge (Ontology tools, IDM and MVD tools) and (2) BIM/GIS data management tools making use or extend that knowledge mainly to realize a design project (BIM/GIS Server + Viewer, Model Checking and Project Requirements tools). This sub chapter presents relevant developments and highlights main features, challenges and typical short comings of selected tools. The tools discussed here have been chosen based on own experiences and preferences, which represent the state of the art in terms of functionality. However, it is not meant to be a comprehensive overview and assessment of available tools due to the diversity of that subject.

2.3.1 Ontologies tools

There exist a large set of commercial and open source software tools supporting the Linked Data approach (semantic web). This chapter will describe a few of these tools, focussing on the ones used in past or longer running projects. The tools can be divided in two types, editors and servers. The editors are mainly intended to view and edit the ontology where the servers focusses on publishing and sharing the data. A server can add/edit the data, but this is done (programmatically) via SPARQL (no user friendly interface for this).

TopBraidComposer (editor)

TopBraid Composer (TBC) is a commercial development tool and it is one of the world's most powerful semantic web modelling tool and used by thousands of commercial customers. The Composer offers comprehensive support for building, managing and testing configurations of ontologies and RDF graphs. Various version of the tool exist where the Standard Edition is a fully featured modelling tool for RDF/OWL graphs and SPARQL queries. The Free Edition is a simple RDF/SPARQL editor with limited features and no commercial support. The Maestro Edition is the most complete Composer that includes all features of the Standard Edition plus additional data import capabilities and support for developing TopBraid applications with tools like SPIN, SPARQLMotion and SPARQL Web Pages and Application Components. Here are just a few of the Composers popular features:

- Visual editors for RDF graphs and class diagrams
- Ability to generate SPARQL "by example" in the graph view
- Automated conversion of spreadsheets, Excel, UML and other data sources
- SPINMap – SPARQL-based ontology mapping tool
- Triples view with support for refactoring triples across different graphs

Fully compliant with W3C standards, TopBraid Composer is implemented as an Eclipse plugin. Its workspace provides a named graph RDF data store. Individual graphs in the workspace can be stored in various ways, including (some functionality requires the Maestro Edition):

- RDF files
- files in any format that TBC can auto-convert to RDF such as spreadsheets and XML
- graphs in external RDF databases
- SPARQL endpoint connections
- RDFa and Microdata web sites
- Relational Databases

Since the composer can connect to relational databases, it also manages dynamic RDF graphs that come from relational data and supports running SPARQL queries over relational data. Users can combine graphs with different persistence by simply dragging and dropping them together.

Although the actual ontologies to be developed within Streamer are not defined yet, expected is that it will be used for requirements and a small part of the data (mainly new data not fitting in existing standards). TopBraid Composer is a valuable tool to create such ontology and allows reading of other ontologies like CMO and/or CB-NL for reusing parts. After creating the ontology TopBraid Composer remains valuable due its SPARQL engine that can be used for developing and testing queries. The queries will be useful to extract/request the relevant information from a semantic data store.

Protégé (editor)

Protégé is a free, open source ontology editor and a knowledge acquisition system. Protégé provides a graphical user interface to define ontologies. It also includes deductive classifiers to validate that models are consistent and to infer new information based on the analysis of an ontology. Like Eclipse, Protégé is a framework for which various other projects suggest plugins. This application is written in Java and heavily uses Swing to create the rather complex user interface. Protégé recently has over 200,000 registered users. Protégé is being developed at Stanford University in collaboration with the University of Manchester and is made available under the Mozilla Public License 1.1.

Protégé also has a web version (WebProtégé). This is also an editor but less complete compared to the offline version. It does not allow all editing options, however it does add collaboration and versioning for developing an ontology. The ontology is also online similar to the servers, but does not support SPARQL. It is purely intended develop a new ontology by share and discussing it. A user can add comments to specific pieces/versions of the model. Also mailing notifications can be set on changes of a specific part of the ontology.

Protégé can be used for creating the Streamer ontology similar as TopBraid Composer. It however misses the SPARQL engine used for developing and testing queries. On the other hand WebProtégé has some functionality that misses in TopBraid Composser and is valuable to Streamer. Different consortium members will be involved in developing the ontology, which benefits from a tool for collaborative ontology editing/development. The editing power of WebProtégé is far less as TopBraid Composer especially Meastro Edition, but they can be used together. Via TopBraid Composer the ontology is edited. After this editing it can be uploaded to WebProtégé and every consortium member can comment on the changes to achieve an ontology accepted by all members.

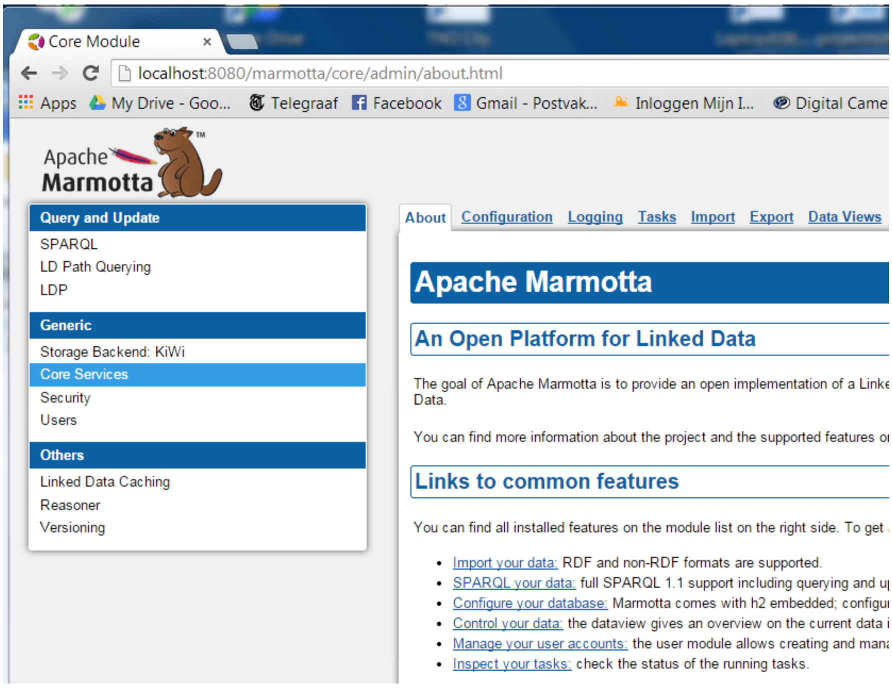
Marmotta (server)

The goal of Apache Marmotta is to provide an open implementation of a Linked Data Platform that can be used, extended and deployed easily by organizations who want to publish Linked Data or build custom applications on Linked Data.

Features of Marmotta server are:

- Read-Write Linked Data
- RDF triple store with transactions, versioning and rule-based reasoning
- SPARQL, LDP and LDPath query
- Transparent Linked Data Caching
- Integrated basic security mechanisms

Marmotta comes as a continuation of the work in the Linked Media Framework project. LMF is an easy-to-setup server application that bundles some technologies such as Apache Stanbol (semantic engine) and Apache Solr (fast enterprise search engine) to offer some advanced services. After the release 2.6, the Read-Write Linked Data server code and some related libraries have been set aside to incubate Marmotta within the Apache Software Foundation. LMF still keeps exactly the same functionality, but now bundling Marmotta too. Apache Marmotta joined ASF Incubator in December 2012, graduated as a Top Level Project in November 2013.



Apache Marmotta

An Open Platform for Linked Data

The goal of Apache Marmotta is to provide an open implementation of a Linke
Data.

You can find more information about the project and the supported features o

Links to common features

You can find all installed features on the module list on the right side. To get

- Import your data: RDF and non-RDF formats are supported.
- SPARQL your data: full SPARQL 1.1 support including querying and u
- Configure your database: Marmotta comes with h2 embedded; configu
- Control your data: the dataview gives an overview on the current data i
- Manage your user accounts: the user module allows creating and man
- Inspect your tasks: check the status of the running tasks.

Figure 10 - Apache Marmotta "RDF Server" example

Streamer needs a system like Marmotta for sharing the project data based on the earlier created ontology. During the use of the ontology data will be created, changed and deleted regularly. A server is the best solution to share such information. Marmotta is such a server that can deal with ontologies, SPARQL and even SPARQL update to modify the data.

Stardog (server)

Stardog is a semantic graph database implemented in Java and supports RDF, OWL 2, SPARQL 1.1 query language and HTTP protocol for binding. Stardog is comparable to Marmotta in functionality but commercial. A free version is available which is limited in the number of triples it can handle, and therefore it was not used in earlier EU projects. More details at: www.stardog.com.

2.3.2 BIM/GIS Server

BIMserver.org

BIMserver.org is a software platform to easily build focused tools based on IFC. BIMserver.org lowers the threshold to build niche applications fast and stable. The BIMserver.org platform gives programmers a flying start with the development of tools using the IFC standard.

The core of the software is based on IFC and therefore knows how to handle IFC data (both IFC2x3 and IFC4). The BIMserver is not a fileserver; data are interpreted and stored as objects in an underlying database. The main advantage of this approach is the possibility to query, merge and filter the BIM data. There are many possibilities to connect to the software (interfaces, API's). This makes it possible to write any other (closed source) application but still use the BIMserver platform underneath.

BIMserver.org has core server features like revisions, authorization, compare, query, model checking, merging, etc. The BIMserver community tries to make the threshold for developers as low as possible: BIMserver has lots of open interfaces and network protocols (soap, PB, json), uses open standards, is built as a plugin framework for easy fine-tuning, has a flexible admin configuration GUI and very good developers documentation and SDKs. These protocols are also all based on the semantic IFC standard. This means the semantics of IFC are represented in the API.

Many (commercial and non-commercial) applications trust BIMserver as their base. In Streamer it can be used for validating data exchange requirements modelled in mvdXML. The BIMserver is capable of reading entities of an IFC model and perform checks on it, which perfectly fit to data validation.

Deegree server

The Deegree project was born in summer 2002 as a consistent follow-up of a research & development project at the Geography Department of the University of Bonn in Germany. Deegree is open source software for spatial data infrastructures and the geospatial web. It includes components for geospatial data management, including data access, visualization, discovery and security. Open standards are at the heart of Deegree. The software is built on the standards of the Open Geospatial Consortium (OGC) and the ISO Technical Committee 211.

It includes the OGC Web Map Service (WMS) reference implementation, a fully compliant Web Feature Service (WFS) as well as packages for Catalogue Service (CSW), Web Coverage Service (WCS), Web Processing Service (WPS) and Web Map Tile Service (WMTS). Since 2000 Deegree has been developed by lat/lon, with the strong intention to make it a community-driven project. A major step to this effect was the acceptance to be an OSGeo project in 2010. Today, Deegree is maintained by several organizations and individuals with a large user base all around the world.

GeoServer

GeoServer was started in 2001 by The Open Planning Project (TOPP), a non-profit technology incubator based in New York. TOPP was creating a suite of tools to enable open democracy and to help make government more transparent. The first of these was GeoServer, since there was a need of sharing spatial data in order to allow citizen involvement in urban planning via the suite of tools.

The GeoServer founders envisioned a Geospatial Web, analogous to the World Wide Web. With the World Wide Web, one can search for and download text. With the Geospatial Web, one can search for and download spatial data. Data providers would be able to publish their data straight to this web, and users could directly access it, as opposed to the now indirect and cumbersome methods of sharing data that exist today.

GeoServer allows you to display your spatial information to the world. Implementing the Web Map Service (WMS) standard, GeoServer can create maps in a variety of output formats. OpenLayers, a free mapping library, is integrated into GeoServer, making map generation quick and easy. GeoServer is built on Geotools, an open source

Java GIS toolkit. There is much more to GeoServer than nicely styled maps, though. GeoServer also conforms to the Web Feature Service (WFS) standard, which permits the actual sharing and editing of the data that is used to generate the maps. Others can incorporate your data into their websites and applications, freeing your data and permitting greater transparency. GeoServer can display data on any of the popular mapping applications such as Google Maps, Google Earth, Yahoo Maps, and Microsoft Virtual Earth. In addition, GeoServer can connect with traditional GIS architectures such as ESRI ArcGIS.

2.3.3 BIM/GIS viewer

There is a number of free applications available, which are able to visualize BIM and GIS models.

BIM viewer

Table 2 lists a selection of free BIM viewers. Besides importing IFC models, some of the viewers are able to import other formats like gbXML and BCF or proprietary formats. Most viewers offer similar display functionality (wireframe, shading), similar navigation modes (examine, fly, walk) and similar information access (project browser, properties). Some of the viewer provide addition functionalities, like clash detection, measurement tools or data enrichment. In order to support collaboration, a few viewers enable the communication via BCF.

Table 2: List of free BIM viewer

Viewer	Import	Download
Bentley Viewer V8i	**IFC** dgn, dwg, dxf	http://www.bentley.com/de-de/products/bentley+view/
BIMSight	**IFC, BCF** dwg, dxf	http://www.teklabimsight.com/
BIM Vision	**IFC**	http://www.bimvision.eu
Constructivity	**IFC** 3DS, Collada, BIM server	http://www.constructivity.com/
DDS-CAD-Viewer	**IFC, gbXML, BCF**	http://www.dds-cad.net/downloads/dds-cad-viewer/
eveBIM Viewer	**IFC**	http://www.cstb.fr/actualites/webzine/editions/octobre-2008/les-rendez-vous-de-la-maquette-numerique.html
FZKViewer	**IFC, gbXML, BCF (**dxf)	http://www.iai.kit.edu/www-extern/index.php?id=2315&L=1
Ifcplusplus	**IFC**	http://code.google.com/p/ifcplusplus/
IFC Viewer	**IFC**	http://rdf.bg/ifc-viewer.php
Solibri Model Viewer	**IFC, BCF**	http://www.solibri.com/products/solibri-model-viewer/
Xbim Xplorer	**IFC**	https://xbim.codeplex.com/releases

GIS viewer

As geospatial information covers a wide range of applications and data specification (e.g. 2D, 3D, raster data, vector data), the list of GIS viewers (Table 3) is focusing on applications, which are able to import 3D CityGML models. As the BIM viewers, all these viewer offer standard display and navigation functionalities. In order to merge different data sources, most of the applications allow importing different 3D format. Geospatial information is often stored and maintained in databases. Therefore, some viewers allow to access data via web services (e.g. OpenStreepMap or OGC Web Services).

Table 3: List of free GIS (CityGML) viewer

Viewer	Import	Download
Aristoteles	**CityGML**, GML, CityGML ADE, dxf, vrml, OGC Web Services	http://www.geo-kiosk.net/explore-3dgeo/download/
Cityvu	**CityGML,** 3DS, Obj	http://3dgis-cityvu.software.informer.com/
FZKViewer	**CityGML**, OSM, GML, KML, OGC Web Services	http://www.iai.kit.edu/www-extern/index.php?id=2315&L=1
LandXplorer	**CityGML**	http://landxplorer-citygml-viewer.software.informer.com/1.0/
tridicon CityDiscoverer Light	**CityGML,** OSM, GML, KML, OGC Web Services	http://www.tridicon.de/download/

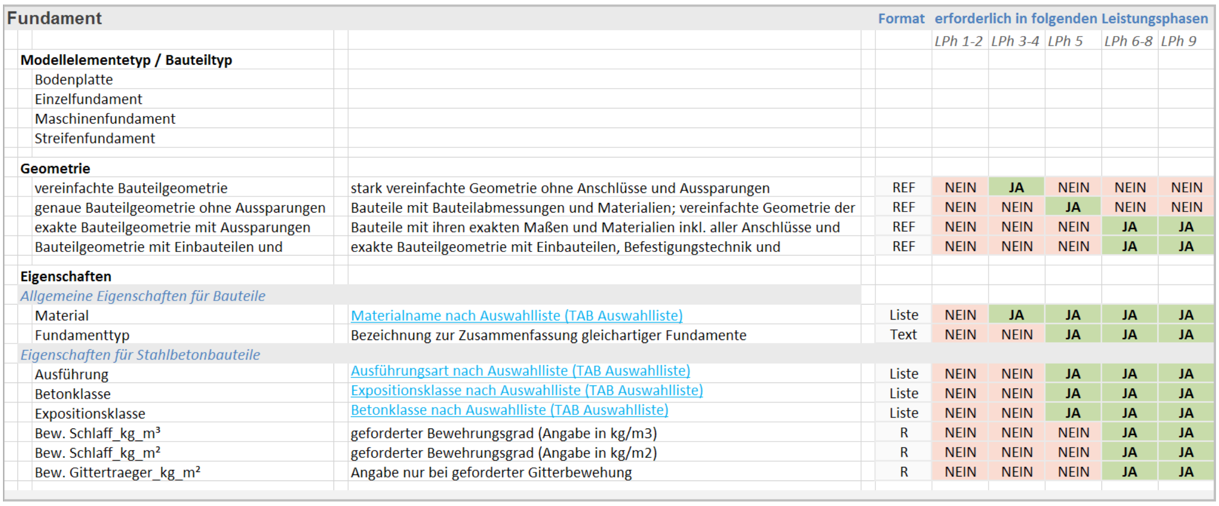
All applications have been downloaded and checked in December 2014.

2.3.4 IDM and MVD tools

Following the IDM/MVD approach as described in chapter 2.2.1 and 2.2.2, there are several steps to be carried out in order to capture and translate business knowledge into IT solutions. Each of those steps require own tools focusing on a specific kind of knowledge. It starts with process definitions according to the BPMN standard for which a couple of mainly commercial tools are available. Main outcome is a diagram that identifies all involved actors, tasks and their dependencies that essentially reflect the data flow. For instance, the process knowledge presented in chapter 3 is modelled with the Bizagi toolset, which is free of charge, easy to use and fulfils all requirements of the IDM method. These diagrams are not only input for the next step but also a basis to discuss the workflow in terms of responsibilities and expected interactions and not at least to communication the scope of developed IT solutions.

One of the main and most challenging parts of the IDM/MVD approach is to clearly specify requirements for the various data flows identified in those process diagrams. This is a rather informal step where the outcome depends on the domain knowledge and special experiences of the people who are defining the so called exchange requirements. This step relates to conceptual modelling, here especially with the focus to identify relevant concepts and properties and relationships. Accordingly, there are a lot of similarities to ontology development and related modelling tools like the TopBraidComposer or Protegé (as elaborated in chapter 2.3.1). However, the barrier for using such tools in particular because of the expected level of formalization is already too high to be used by the addressed audience.

Instead, a simple tabular form as shown in Figure 11 is typically used to capture that kind of knowledge, which can be developed with Microsoft Excel or any other spreadsheet tool that people are familiar with. While its beauty is in its simplicity it also comes with a lot of drawbacks especially when it comes to maintenance, reuse of definitions and collaboration. For instance, experiences using such tables show that there are many property definitions that are reused with no or only minor adjustments. They are typically copied between different sheets, which is quite reasonable to improve readability of the various concept definitions but is difficult to manage in case of changes. Also, there are no possibilities to check consistency of definitions, or better to identify contradictions, nor to use more advanced queries to filter or export the data. Further data evaluation and links to more formal specifications like mvdXML definitions would enable to integrate with the next step, i.e. the mapping definition to a data structure like IFC.



Fundament		Format	erforderlich in folgenden Leistungsphasen				
			LPh 1-2	*LPh 3-4*	*LPh 5*	*LPh 6-8*	*LPh 9*
Modellelementetyp / Bauteiltyp							
Bodenplatte							
Einzelfundament							
Maschinenfundament							
Streifenfundament							
Geometrie							
vereinfachte Bauteilgeometrie	stark vereinfachte Geometrie ohne Anschlüsse und Aussparungen	REF	NEIN	**JA**	NEIN	NEIN	NEIN
genaue Bauteilgeometrie ohne Aussparungen	Bauteile mit Bauteilabmessungen und Materialien; vereinfachte Geometrie der	REF	NEIN	NEIN	**JA**	NEIN	NEIN
exakte Bauteilgeometrie mit Aussparungen	Bauteile mit ihren exakten Maßen und Materialien inkl. aller Anschlüsse und	REF	NEIN	NEIN	NEIN	**JA**	**JA**
Bauteilgeometrie mit Einbauteilen und	exakte Bauteilgeometrie mit Einbauteilen, Befestigungstechnik und	REF	NEIN	NEIN	NEIN	**JA**	**JA**
Eigenschaften							
Allgemeine Eigenschaften für Bauteile							
Material	Materialname nach Auswahlliste (TAB Auswahlliste)	Liste	NEIN	**JA**	**JA**	**JA**	**JA**
Fundamenttyp	Bezeichnung zur Zusammenfassung gleichartiger Fundamente	Text	NEIN	NEIN	**JA**	**JA**	**JA**
Eigenschaften für Stahlbetonbauteile							
Ausführung	Ausführungsart nach Auswahlliste (TAB Auswahlliste)	Liste	NEIN	NEIN	**JA**	**JA**	**JA**
Betonklasse	Expositionsklasse nach Auswahlliste (TAB Auswahlliste)	Liste	NEIN	NEIN	**JA**	**JA**	**JA**
Expositionsklasse	Betonklasse nach Auswahlliste (TAB Auswahlliste)	Liste	NEIN	NEIN	**JA**	**JA**	**JA**
Bew. Schlaff_kg_m^3	geforderter Bewehrungsgrad (Angabe in kg/m3)	R	NEIN	NEIN	NEIN	**JA**	**JA**
Bew. Schlaff_kg_m^2	geforderter Bewehrungsgrad (Angabe in kg/m2)	R	NEIN	NEIN	NEIN	**JA**	**JA**
Bew. Gittertraeger_kg_m^2	Angabe nur bei geforderter Gitterbewehung	R	NEIN	NEIN	NEIN	**JA**	**JA**

Figure 11: Table for capturing exchange requirements (source AEC3).

The tools that can be used to maintain the mapping definitions depend on the used data structure and underlying technology. For the IFC data structure (see chapter 0), buildingSMART provides the IFC documentation generator tool[17] that does not only enable to define the relevant subset of IFC using the mvdXML specification (see chapter 2.2.2) but also to generate a complete documentation that is aligned with the content and layout of the official IFC documentation and goes into further details where necessary. An export to mvdXML would then enable to check if all required data is contained in an IFC file or if something is missing. A first prototype implementation of such checking service (see also next chapter) is included in IFC Doc tool, which generates an error report in a table format.

2.3.5 Model Checking

The BIM based way of working presents several advantages and one is the possibility for different teams to work in parallel on the same project. Arriving at a given level of maturity or advancement, it is usually necessary to put the various models together and check their consistency. This checking is ensured by dedicated tools and Solibri Model Checker (SMC) is one of these commercial solutions.

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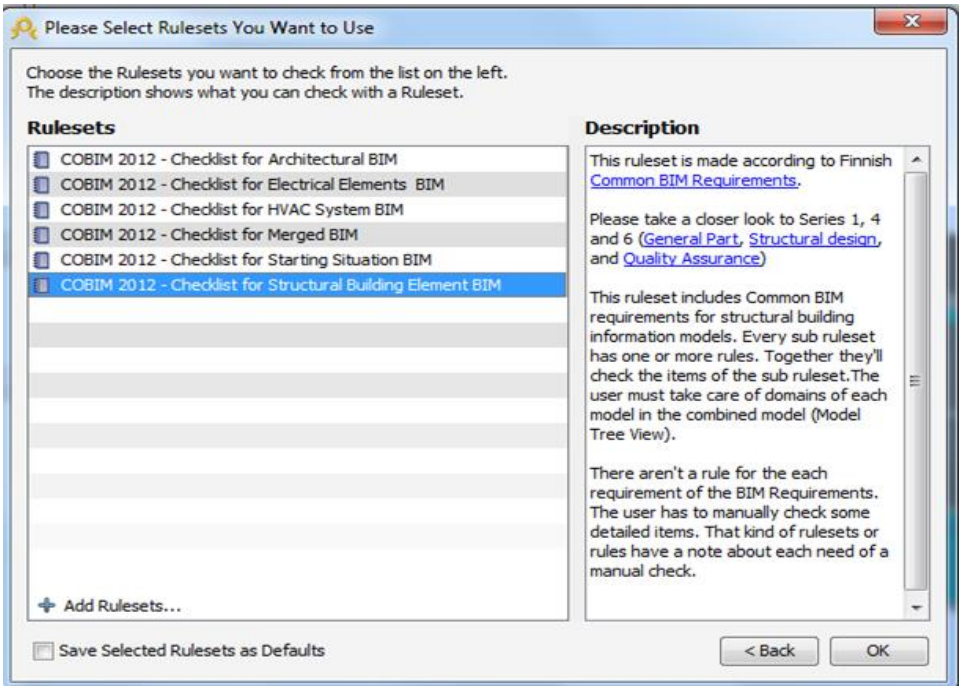
[17] Short IFC Doc tool, which is available free of charge at:
http://www.buildingsmart-tech.org/specifications/specification-tools/ifcdoc-tool/ifcdoc-beta-summary

SMC allows the verification of BIM models based on the definition of rulesets. According to the content of these rulesets, various aspects of the BIM model could be studied. In the frame of a Finnish project called COBIM, several rulesets have been defined (see Figure 12):

- Architectural
- Electrical
- HVAC
- Structural
- Pre check for Energy Analysis



Please Select Rulesets You Want to Use

Choose the Rulesets you want to check from the list on the left.
The description shows what you can check with a Ruleset.

Rulesets

- COBIM 2012 - Checklist for Architectural BIM
- COBIM 2012 - Checklist for Electrical Elements BIM
- COBIM 2012 - Checklist for HVAC System BIM
- COBIM 2012 - Checklist for Merged BIM
- COBIM 2012 - Checklist for Starting Situation BIM
- COBIM 2012 - Checklist for Structural Building Element BIM

Description

This ruleset is made according to Finnish Common BIM Requirements.

Please take a closer look to Series 1, 4 and 6 (General Part, Structural design, and Quality Assurance)

This ruleset includes Common BIM requirements for structural building information models. Every sub ruleset has one or more rules. Together they'll check the items of the sub ruleset.The user must take care of domains of each model in the combined model (Model Tree View).

There aren't a rule for the each requirement of the BIM Requirements. The user has to manually check some detailed items. That kind of rulesets or rules have a note about each need of a manual check.

☐ Save Selected Rulesets as Defaults

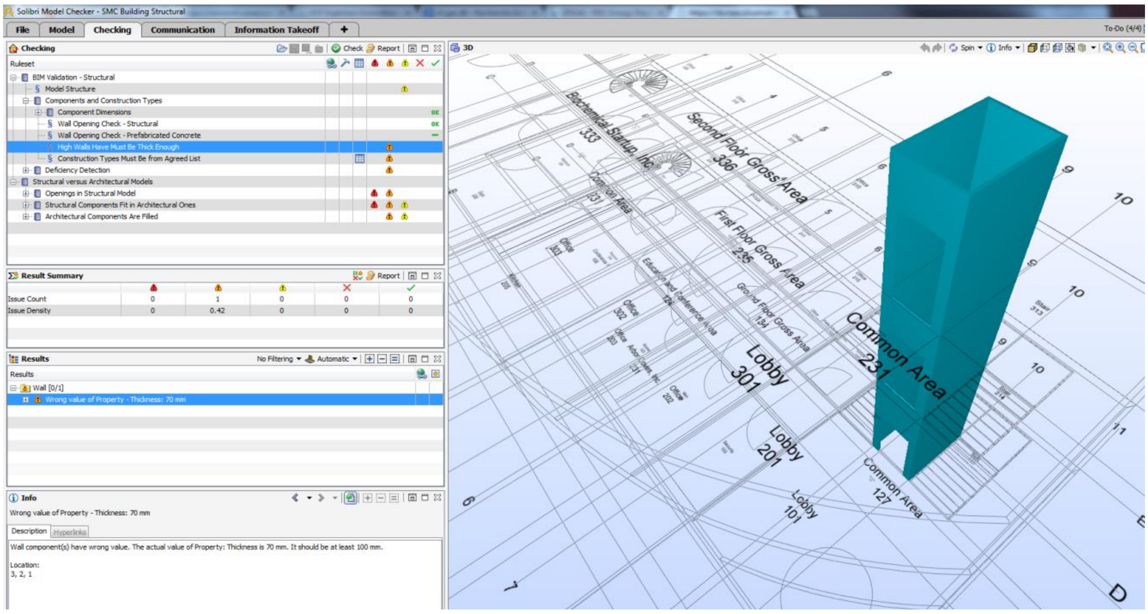
Figure 12: Ruleset "Cobim 2012" (cf. Finnish Common BIM Requirements)

From a very concrete point of view, these rules are assertions that the model has to follow in order to fulfil the requirements.

For the case of the structural validation the list of rules to check is as follow:

- Walls Must Have at Least Minimal Dimensions
- Slab Dimensions Must Be Within Sensible Bounds
- Column Dimensions Must Be Within Sensible Bounds
- Beam Dimensions Must Be Within Sensible Bounds
- Wall Opening Check - Structural
- Wall Opening Check - Prefabricated Concrete
- High Walls Have Must Be Thick Enough
- Construction Types Must Be from Agreed List

SMC allows the user to translate these rules and check them against the BIM model to be verified. The result is presented in a graphical way as illustrated in Figure 13.



Ruleset

- BIM Validation - Structural
  - § Model Structure
  - Components and Construction Types
    - Component Dimensions — OK
    - § Wall Opening Check - Structural — OK
    - § Wall Opening Check - Prefabricated Concrete — –
    - § High Walls Have Must Be Thick Enough
    - § Construction Types Must Be from Agreed List
  - Deficiency Detection
- Structural versus Architectural Models
  - Openings in Structural Model
  - Structural Components Fit in Architectural Ones
  - Architectural Components Are Filled

Result Summary

	⚠	⚠	⚠	✗	✓
Issue Count	0	1	0	0	0
Issue Density	0	0.42	0	0	0

Results

No Filtering ▾ Automatic ▾

- Wall [0/1]
  - Wrong value of Property - Thickness: 70 mm

Info

Wrong value of Property - Thickness: 70 mm

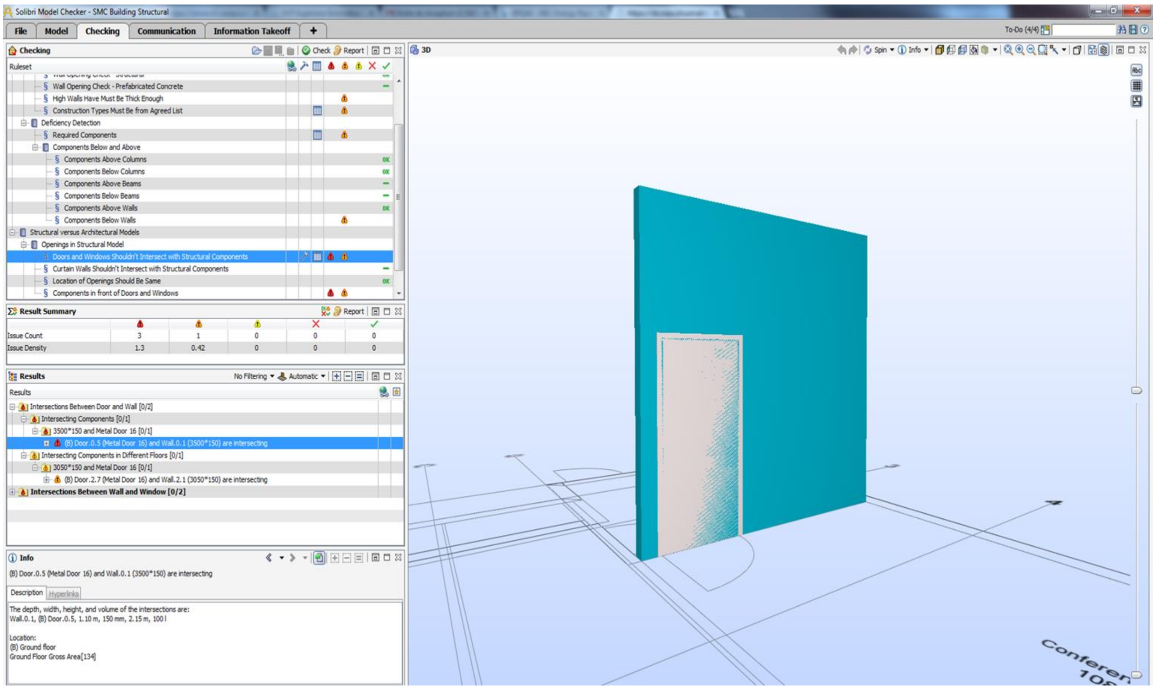
Description | Hyperlinks

Wall component(s) have wrong value. The actual value of Property: Thickness is 70 mm. It should be at least 100 mm.

Location:
3, 2, 1

Figure 13 : Example of the rule “High wall must be thick enough”

But some more complex rules can be also checked like for the openings. For instance, it can be verified that “Openings” in structural model are at the same place of the “doors”, “windows” or “empty openings” in the architectural model. An example is shown in Figure 14.



Ruleset

- § Wall Opening Check - Prefabricated Concrete — –
- § High Walls Have Must Be Thick Enough
- § Construction Types Must Be from Agreed List
- Deficiency Detection
  - § Required Components
  - Components Below and Above
    - § Components Above Columns — OK
    - § Components Below Columns — OK
    - § Components Above Beams — –
    - § Components Below Beams — –
    - § Components Above Walls — OK
    - § Components Below Walls
- Structural versus Architectural Models
  - Openings in Structural Model
    - Doors and Windows Shouldn't Intersect with Structural Components
    - § Curtain Walls Shouldn't Intersect with Structural Components — –
    - § Location of Openings Should Be Same — OK
    - § Components in front of Doors and Windows

Result Summary

	⚠	⚠	⚠	✗	✓
Issue Count	3	1	0	0	0
Issue Density	1.3	0.42	0	0	0

Results

No Filtering ▾ Automatic ▾

- Intersections Between Door and Wall [0/2]
  - Intersecting Components [0/1]
    - 3500*150 and Metal Door 16 [0/1]
      - (B) Door.0.5 (Metal Door 16) and Wall.0.1 (3500*150) are intersecting
  - Intersecting Components in Different Floors [0/1]
    - 3050*150 and Metal Door 16 [0/1]
      - (B) Door.2.7 (Metal Door 16) and Wall.2.1 (3050*150) are intersecting
- **Intersections Between Wall and Window [0/2]**

Info

(B) Door.0.5 (Metal Door 16) and Wall.0.1 (3500*150) are intersecting

Description | Hyperlinks

The depth, width, height, and volume of the intersections are:
Wall.0.1, (B) Door.0.5, 1.10 m, 150 mm, 2.15 m, 100 l

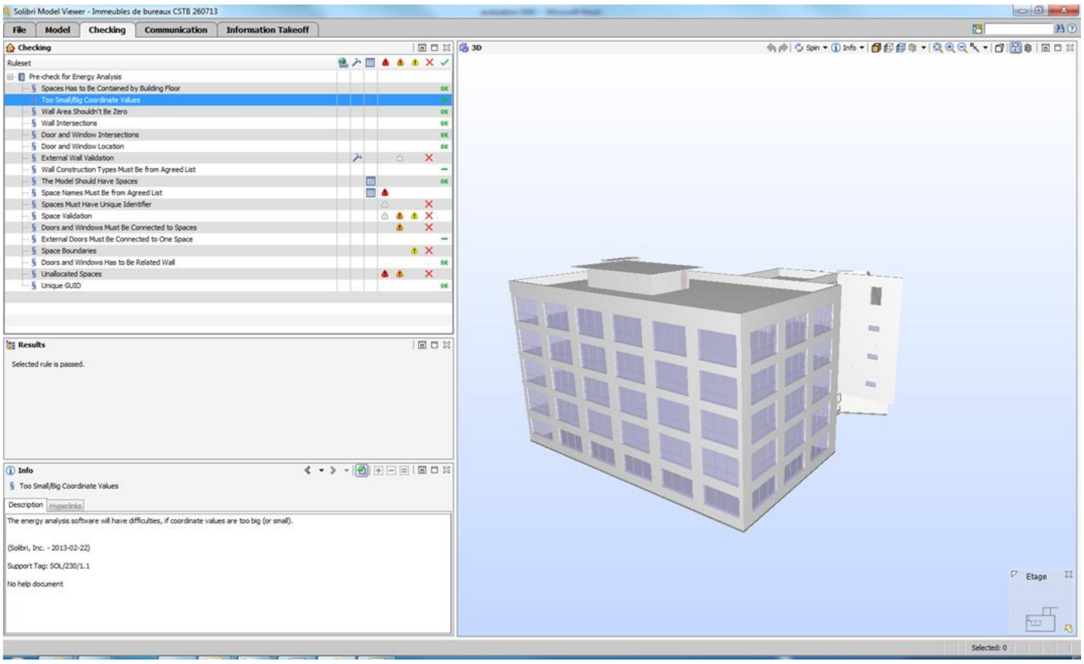
Location:
(B) Ground floor
Ground Floor Gross Area[134]

Figure 14 : Detection of several intersections between “elements”, “walls” and “windows”

It is worth noticing that SMC could also be used to check to readiness/completeness of a BIM model to be used for Energy calculation.

Below is a specific example as a pre-check for a specific energy analysis software, see Figure 15. Other software may have different requirements for the entry model, and thus some rules may be ignored and others added depending on the software used.

- Spaces Has to Be Contained by Building Floor
- Too Small/Big Coordinate Values
- Wall Area Shouldn't Be Zero
- External Wall Validation
- Wall Construction Types Must Be from Agreed List
- The Model Should Have Spaces
- Space Names Must Be from Agreed List
- Spaces Must Have Unique Identifier
- Space Validation
- Doors and Windows Must Be Connected to Spaces
- External Doors Must Be Connected to One Space -Space Boundaries
- Doors and Windows Has to Be Related Wall
- Unallocated Spaces
- Unique GUID



Pre-check for Energy Analysis
- Spaces Has to Be Contained by Building Floor — OK
- Too Small/Big Coordinate Values
- Wall Area Shouldn't Be Zero — OK
- Wall Intersections — OK
- Door and Window Intersections — OK
- Door and Window Location — OK
- External Wall Validation — ✗
- Wall Construction Types Must Be from Agreed List — –
- The Model Should Have Spaces — OK
- Space Names Must Be from Agreed List
- Spaces Must Have Unique Identifier — ✗
- Space Validation — ✗
- Doors and Windows Must Be Connected to Spaces — ✗
- External Doors Must Be Connected to One Space — –
- Space Boundaries — ✗
- Doors and Windows Has to Be Related Wall — OK
- Unallocated Spaces — ✗
- Unique GUID — OK

Selected rule is passed.

§ Too Small/Big Coordinate Values

The energy analysis software will have difficulties, if coordinate values are too big (or small).

(Solibri, Inc. - 2013-02-22)

Support Tag: SOL/230/1.1

No help document

Figure 15: Ruleset pre check for Energy Analysis

3. Identification of use cases for hospital design

Chapter 3 of this deliverable examines process related requirements for hospital design. It provides information of the design flow process to be used in the continuing work in WP5 ”Semantics-driven design method” and as basis for the development work in WP4 “Participatory design framework” – especially task 4.1 “Collaborative process of semantic-driven design” – and WP6 “Interoperable design tools” – especially in the development of a design configurator in task 6.1 “Semantic design configurator”. Further information on the design process and its design flow can be found in the Appendix 1.

The use cases discussed in this chapter apply the IDM methodology described in chapter 2.2.1 and thus are adding relevant process knowledge for hospital design[18]. The use cases describe how buildings and its functions are developed and, once translated to a model view definition (see chapter 2.2.2) how the required design data shall be represented and checked in different models like IFC, gbXML or others (see chapter 2.1).

The chapter first defines the processes, then identifies the relevant data flows and finally details the exchange requirements. The overall aim of this chapter is to specify relevant domain knowledge in order to support and improve hospital design processes. In most cases these kinds of specification are as yet missing and thus have to be extracted from implicit knowledge of domain experts. However, it is more than a specification of best practices because required process knowledge is intended to be applicable for the novel BIM methods and new solutions to be developed in the Streamer project. Accordingly, the specification presented in this chapter can be seen as a first proposal of TO-BE processes that have to be refined throughout WP5 activities and coordinated with other tasks.

3.1 Process Definition

This sub-chapter identifies relevant stakeholders, design phases and elaborates on “Program of Requirements” (PoR) processes. It explains process mapping with BPMN using activities, resources, dependencies and information flows as a tool to define and link the construction process to the design process with BIM (chapter 2.2).

3.1.1 Process mapping

Following the IDM methodology the first step is to specify processes. For this a simplified version of the Business Process Modelling Notation (BPMN)[19] is used. BPMN is an accepted standard developed by the Object Management Group (OMG) that is supported by many commercial tools. Within Streamer the free software Bizagi was chosen (http://www.bizagi.com/en) to define our process maps, mainly because it is simple to use, free of charge and supports all required concepts. It is important to note that the focus within the IDM methodology is to identify information flows and not necessarily to automate workflows, i.e. to translate to the Business Process Execution Language (BPEL). Therefore the, process specification can be less formal and more flexible.

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[18] In more formal words: experiences from domain experts are added using the ontological commitment of the IDM method.
[19] http://www.bpmn.org/

The BPMN method is a graphical representation for specifying business processes in a business process model. Four basic categories of elements are described (see Figure 16):

- Flow objects – main graphical elements defining the behaviour of the process, e.g. events, activities or gateways.
- Connecting objects – providing connections between the flow objects, indicating the processing order. For example, sequence flows, message flows and associations.
- Swim lanes or “Pools”– which are used to group the modelling elements in a process. Each lane is assigned an actor, for example, client, architect or facility management, (which may be an individual, department, division, group, machine, entity, and so on), or even a phase or stage in a process, that is somehow responsible for the activity or work described in the lane. A “Pool” can consist of several lanes/actors/…, for example: The “Client” pool can consist of “Management” lane and “End users” lane.
- Artefacts – that are used to provide additional information about the process steps. They can consist of data objects, groups and annotations.

A process is described by activities at various levels: A higher level process can be broken down into several lower level processes, e.g. reflecting different project phases. This could be done by introducing (1) independent sub-processes, (2) a link between the processes, or (3) embedded processes, which groups several steps together within a particular process (as a sub-process).

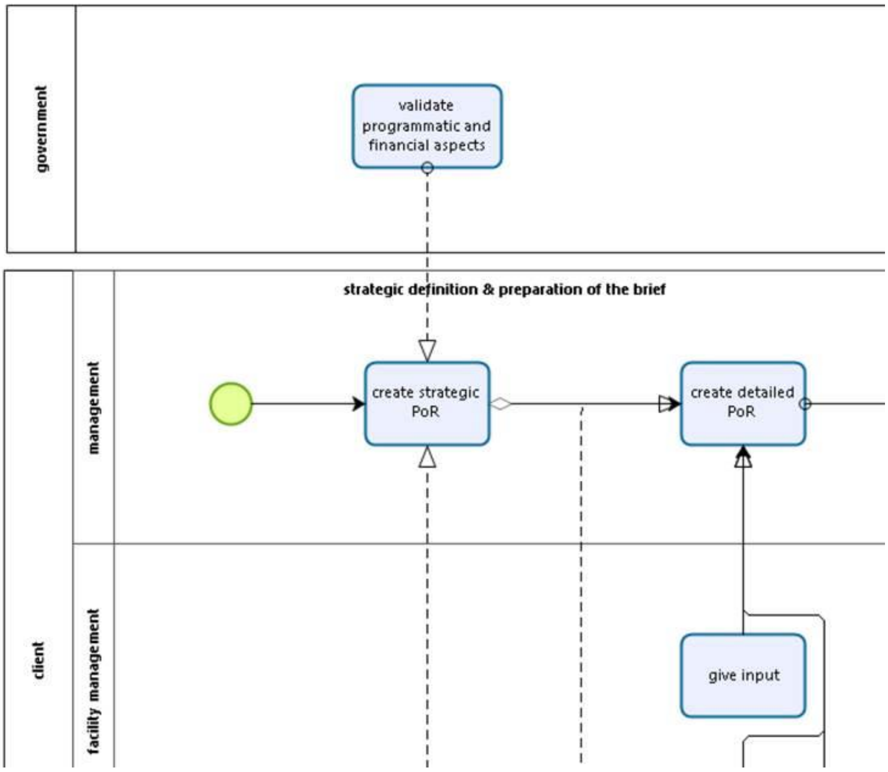

Figure 16: Example: Mapping project initiation using BPMN

Within the lanes (or pools) the information is always displayed in a logical and chronological order. In Streamer the swim lanes (or pools) represent actors or roles that correspond, generically, to the organization deployed in the design phase in constructing or renovating a hospital:

- Society (represented by a lane: government)
- Client/Hospital (lanes: management, facility management, end users)
- Consultants (management or "hospital-related")
- Design & build team (lanes: BIM management, urban designer, architect, building services engineer, structural engineer, interior designer, contractor)
- Information (lanes: BIM, graphical model, non-graphical data and documentation)

3.1.2 Project stakeholders

Project participants include individuals and organizations that are actively involved in the project, or whose interests may be affected as a result of project execution or project completion. They are contributing to and/or being affected by the construction project decision making process. The participants, or "roles", can have double functions: For example, project developer can also be the investor or the builder, and the client can also be the end-user. Commonly, all parties play different roles in the construction process. The composition of roles in a project changes over time but basically consist of four groupings in the design phase:

- **Society: Government Authorities**

  They set and control that laws and regulations are followed. The interests of the authorities are essentially to create safe and healthy buildings. Building rights and restrictions are set through town planning and documented in town planning charts and descriptions and the authorities verify that those requirements are followed. In most countries, the government (partially) finances the construction and operation of hospitals.

- **Client/Hospital**

  "Client" can imply many different roles; basically, the client is a person or an organization for whom/which the project is carried out. Often the client sets the overall PoR as well pays for the work to be executed. End users and patients are often represented in so-called steering groups. Facility management can be very influential in the design process. Their task is to safeguard the operational requirements and costs related to the design. Hospital management is responsible for the main decision making and coordinating the design process in their own organization.

- **Consultants**

  Choices for hiring external consultants vary in every project. They can be contracted to advice on the development of the PoR in a very early stage, or to manage costs and planning in the design stage. In projects with high complexity, consultants can be hired to evaluate the compatibility of the design with logistical processes.

- ***Design & build team***

  The design & build team consists of designers, technical specialists and contractor. They are responsible for the development, from programming and design to construction and turnover. The project team develops and tests different solutions and provides steering group with basis for decisions. The BIM manager (or similar) coordinates the model-based and integrated design process (design teams) providing exchangeable coordinated, updated information throughout all stages.

3.1.3 Design phases

Each construction project follows a common route from initiation: In the early stage, client, consults and specialists come together to define project objectives and requirements, and produce alternative solutions. Client/steering group decides on project realization. If the client decides to continue, the project team produces construction design and production commences. After handover, the project can be evaluated. In order to reach best possible results, it is essential that the end users and patients are consulted or represented throughout the process.

Design phase including boundaries, and details the tasks and outputs required at each stage –as from the UK model for the building design and construction process “RIBA Plan of Work 2013” (www.ribaplanofwork.com). The RIBA Plan of Work 2013 is digital tool allowing users to customize the processes by providing the option to select and define, for example, the procurement route, combine certain work stages, the use of BIM and choose the optimum time to go for planning application. The core objectives of each stage, however, are fixed and cannot be changed.

Using this structure allows the work in Streamer to map out the information structure to find solutions to better streamline the design work –the supporting information and data and the information exchange using a model-based design approach. The RIBA Plan of Work 2013 consists of eight work stages identified by the numbers 0-7 (see Figure 17), following the logics of: Brief – Concept – Developed design.

0	Strategic definition
1	Preparation and brief
2	Concept design
3	Developed design
4	Technical design
5	Construction
6	Handover and close out
7	In use

Figure 17: The eight stages of RIBA Plan of Work 2013

The Design phase comprises stages 0-4 and is strongly connected to the work and responsibilities in the additional stages. Each stage is outlined with clear boundaries, and details the tasks and outputs required according to Core Objectives, Procurement, Programme, (Town) Planning, Suggested Key Support Tasks, Sustainability Checkpoints, and Information Exchanges (at stage completion).

3.1.4 Programme of Requirements

The Programme of Requirements (PoR) forms the basis of the client's goals and expectations for the project. It is one of the first and most important documents in the design process. It often includes the room programme (list of required rooms with additional information such as minimum area, height or neighbourhood relationships to other required rooms), equipment requirements (cooling systems of a certain performance) and general requirements like desired energy level or sustainability certificate.

A PoR should be carefully put together and;

- be based on realistic turnover predictions for hospital department / functional area,
- represent the core beliefs of the organization,
- mention the long-term ambitions,
- be supported by the stakeholders,
- contain detailed information for the design team

Current state-of-the-art tools are able to capture the PoR using database technology and are able to synchronize with the geometrical BIM. In Deliverable 4.3 of Streamer, two of these tools are described in detail: dRofus (from Norwegian company Nosyko AS) and Briefbuilder (from Dutch company ICOP).

The client may also specify his information requirements (in the UK referred to as the EIR, Employer's Information Requirements). Whilst primarily focused at efficient and complete handover information, earlier information deliverables are also anticipated for example for functional and cost review. Aspects of these requirements may cascade and be amplified down through the design chain and the supply chain. A key aspect of the EIR is the adoption of a digital 'Plan of Work' (dPoW), detailing information expectations:

- **Context** – the scope or mandate of the dPoW
- **Stage and Purpose** (for example stages 0-7 and any sub-purposes within the stages)
- **Actor** – client, design or construction experts
- **Role** – responsible for, accountable for, consulted on, informed of
- **Object** – the system, zone, product or space
- **Attribute** – property, representation or measurement

The dPoW is intended to replace course Level of Detail (LoD) grades (such as the LoD100-500) with verifiable requirements. It is important to differentiate the PoR as stating the required values (provide 5 office rooms each with a net area of 20m²) from the information requirement (architect shall provide the information about room type and net room area for each room object in its BIM deliverable).

3.1.5 Information provided by the consultants

Management consultants act as a link between the client and other stakeholder groups in order to aid in business development, strategic planning and project execution. In a "typical" healthcare construction project, it is an advisory role (construction management consulting, project planning) aiming on meeting the client's goals, requirements and expectations during every phase of the project lifecycle towards a functionally and sustainable (financial, environmental and social) optimized end product. In the design stage, the management consultants serve as a resource to assist the client in developing the specific requirements for the project.

A PoR details all objectives, spaces, services and equipment. Typically, the client reviews and contributes to the development of the PoR together with consultants, the steering group, and other consultants and expertise. In the case of technically complex situations, additional specialists and expertise is called in to consult. For example, future staff (end users) contributes to develop performance requirements and equipment lists. The design & build team uses the PoR together with any other applicable requirements and regulations and schedule and the construction budget, as the basis for their design work. Through-out design, the (management) consults link client and its interests to project group, monitors the subsequent development in order to ensure that initial targets and requirements are met. They provide client with basis for decisions and notifications of (relevant) design changes. The involvement of the consultants varies and can also include, for example, working with the project group propose design and construction alternatives, make recommendations on design improvements, construction technology, schedules and construction economy, coordinate procurements and the work of contractors, changes, legal issues, conforming design requirements and other project related services as required by the client and/or steering group. It is, however, important to recognize that the role of the consultants also varies, because the nature of the organizational structure changes in each stage within a project.

3.1.6 The importance / advantages of having an up-to-date BIM available

BIM as a project delivery method is challenging, multi-disciplinary and multi-participant as sharing, retrieval, and updating of information are performed in a distributed manner. The BIM models act as a single source of building information for all processes providing coordinated, reliable information about a project throughout all phases. The biggest win, as well as the biggest challenge here, is to get the design team – and its individuals – to actually use and feel ownership of the BIM design data. Therefore, involving everyone in the process, providing quick access to the information, and keeping the information updated is essential.

The BIM manager has design-related responsibilities – e.g. setting up BIM work flow, model coordination and checking, information exchange –including coordinating and checking that information is interoperable and up to date. Besides guiding the project team, the BIM manager also coordinates design decisions published in a manner so it can be checked against the PoR and initial project objectives to ensure that they are aligned with the Project Programme. Reversed, the feedback from decision-makers reaches design teams for them to revise content as required. The design teams remains responsible for updating their design and to provide basis to update schedule and costs.

For BIM to be truly integrated into the design process it is imperative to maintain a real time linkage between the client/steering group and the design teams ensuring compliance with design intent and project requirements. Although important throughout the process the consequences of working unconnected is greater in the early stages when decisions are made on system level.

3.1.7 The BIM-coordination document

For added value use of BIM and 3D modelling, it has necessitated the development of a well-defined, organized, consistent and repeatable framework for coordination. This BIM spatial coordination document will pro-vide guidance to companies and individuals involved in the BIM coordination of HVAC and the buildings. Because the difficulty of no single document can convey every aspect required to complete a BIM project, therefore, the primary focus on the BIM-coordination document is to outline the HVAC and building spatial coordination process using 3D and BIM technology. When used as intended, this document will provide assistance with team structure, definition of roles and responsibilities, recommendations for technical and IT considerations, social structure and accountability.

This is important especially in interdisciplinary interfaces. For instance, when running clash detection against an architectural model, it often becomes beneficial to regard the model as different systems for issue identification. It becomes beneficial to run a clash against the ceiling search set and the MEP systems. Other architectural systems are likewise clashed against other disciplines.

3.1.8 Creation of “as-built” BIM

With the proliferation of BIM in architectural design, there will be a rapidly increasing need to create accurate as-built BIM data for existing buildings. Having an accurate as-built model of the existing structure allows owners to visualize and analyse proposed retrofit solutions and ensures that the retrofit meets the owner's requirements and provides the best value.

There are a number of methods in which an existing structure can be accurately reproduced as a model, but in general there are two:

1. BIM ready model from 3D Laser Scanned point cloud data:
   It is now common practice for Architectural surveying companies to laser scan structures/buildings. This technique produces a point cloud consisting of billions of points representing real world coordinates that build up the environment from everything the scanner sees. Although geometrically correct, these 3D models are not “semantic” in the same way as a BIM; the building elements are not classified as roof, floor, wall, etc., they are just a volume.
2. BIM ready model from 2D CAD drawings:
   It is extremely likely that 2D drawings have already been completed for a building from previous years. It may be extremely cost effective to produce a 3D BIM ready model from this already worked up and finished data. This is generally the fastest way to produce a model as the majority of the analysis of the data has already been done. If these drawings have already been completed then it is generally more cost effective than conducting another survey (assuming nothing has changed since they were drawn).

3.1.9 Phase Document

The project team records the evidence of its work in a set of phase documents. The approved project work pattern determines the required documents, which compose the set of phase document.

3.1.10 Maintenance of the "in-use BIM"

BIM design project data is created, gathered and accumulated by the project group/design teams during the planning, design, and construction stages of the project. This data eventually forms a documentation of "last design decisions made" also incorporating design modifications during construction – reflecting as-built conditions. Ideally, this includes all relevant building component information such as manuals and specifications, product data and details, and other product and manufacturer information. This as-built model is a resource that can be used by facility owners and facility managers to control operation and maintenance tasks throughout the lifecycle of the building as well as repairs, extension works and retrofits. However, depending on the kind of activities only few data might be relevant to support those activities. Thus, FM handover typically focus on a subset of whole BIM data as for instance defined in the COBie view.

During a buildings lifespan there are many firms contracted to provide a range of FM or structural services, both in-house as external firms, resulting in a great amount of information that needs to be incorporated to the BIM model to keep it maintained and up to date, creating an "operational BIM". However, in-house services are usually not suited for handling "BIM data" as they most commonly have limited BIM knowledge and as they are often contracted in periods of a couple of years (compared to the expected lifespan of the building, +50 years). Thus, there can be many different service providers updating the BIM model likely to cause numerous inconsistencies in the way information is captured and updated by each provider making information increasingly less reliable over the years.

In order to keep a BIM model operational, facility owners and operators need to adopt BIM technology as a way of documenting the building and improving the performance and costs over its entire life cycle. The facility owner must allocate funds to update information and maintain a current "Operational set". It must be clear who is responsible for the as-built model and the operational model including changes over time. Building data in a digital form is preferable, as it makes information instantly available for operators and planners. Integrating building systems/FM technology with BIM data allows data to be continuously updated over the life of the building (data standards and interoperability). Either the in-house staff is trained to update and maintain BIM data or FM or any other service provider updates the BIM model automatically as part of their contractual responsibilities. We can also see a new kind of service provider emerging, specialists who take on responsibility for updating "wide-ranging" BIM data and ensuring its accuracy over time.

3.2 Data-flow between design team models

Within Streamer, five major scale levels have been defined: 1) neighbourhood, 2) building, 3) functional area, 4) room, and 5) component. In both the PoR and the modelling environment, these scale levels are related to different objects and information. This means that for every scale level the data-flow process is somewhat different.

Below, the dataflow from the PoR to the model to the analysis software is illustrated on these scale levels. Information exchange between the design team partners is briefly described. This topic will be covered in more detail in Task 5.2 of Streamer, where a more formal way of capturing data and information in the design process is developed.

3.2.1 Neighbourhood scale level

Although this topic will be covered in more detail in Task 2.7 (health care campus area) and Task 2.8 (neighbourhood area) of Streamer, we can here summarize the approach. The Rotterdam Energy Approach and Planning (REAP) becomes a logical approach of matching energy and different scale level of building and city. REAP was developed to support energy-neutral urban planning in a structured, incremental way (see Figure 18).

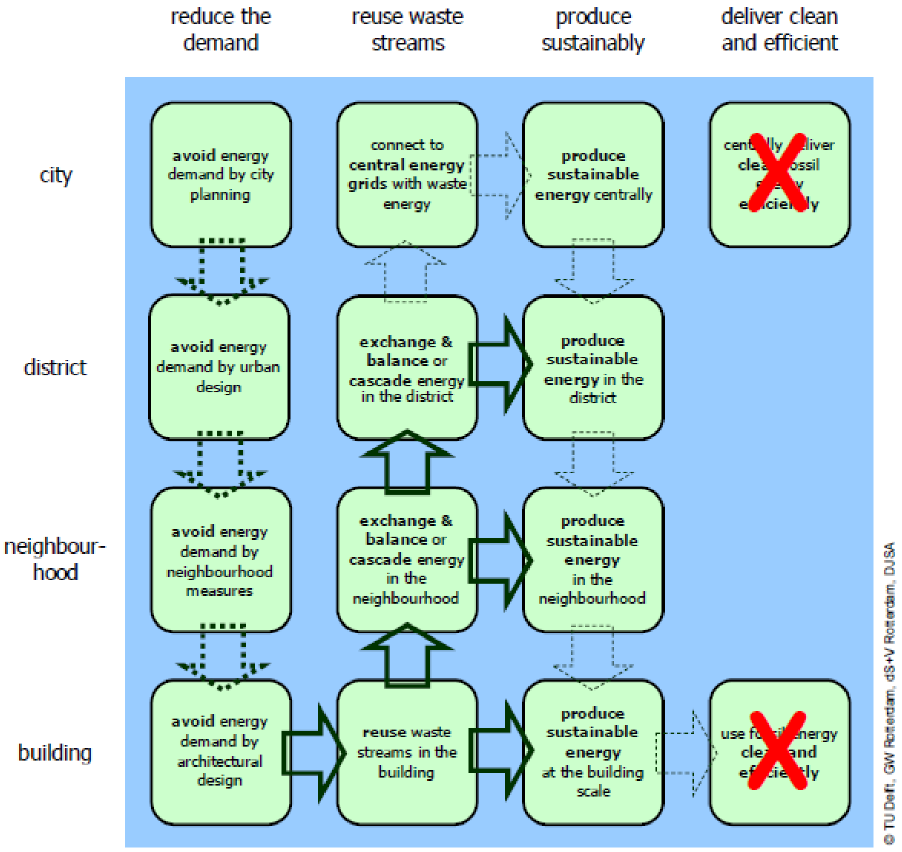

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Figure 18: REAP visualisation

The main scope of this approach on different scale level is maximizing efficiency of energy usage differentiate the context of logical prioritizing "Trias Energetica" (see Figure 19).

1. Reduce demand;
2. Reuse waste streams;
3. Produce sustainably

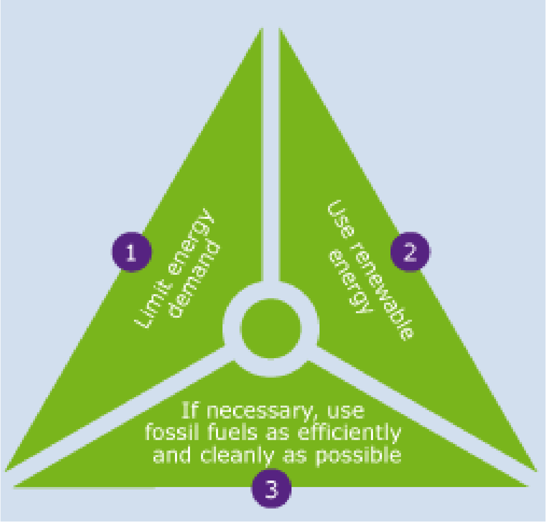


Figure 19: Trias Energetica

In this REAP visualization, ‘neighbourhood’ is meant by around the building(s), on a quarter of the city. As we mean health care district. The District level is the external surrounding of the health care district. The playing field of synergy between building and neighbourhood energy systems is marked by the green circle. Because inter building energy exchange and generation/storage of energy would be in between buildings by connection at a grid.

The two subjects outside the building with most influence on the energy usage are urban planning and district heating/cooling system. The required input for a measure of energy reduction is both demand building energy usage or demand energy usage of the health care campus (from GIS) and a potential (existing) source on the campus (from GIS). By matching both demand and potential source a well-founded decision can be made. See also Task 2.7 for further details.

3.2.2 Building scale level

In the PoR, some general descriptive information can be provided, for example relating to sustainability targets, or minimum glazing percentages / thermal insulation properties of the facades. The building scale level is represented in the modelling environment by the mass. In an early design phase, this shape can be easily manipulated by the architect. Researched tools Briefbuilder and dRofus do not yet support synchronization level between the PoR and the mass. However, within the model, information can be attached to these masses, such as layer type (one of the Streamer labels, as described in D1.1), building energy properties and glazing percentage. Some modelling tools have their own energy analysis tools, which rely on internal energy data. This requires energy settings to be made in the architectural model.

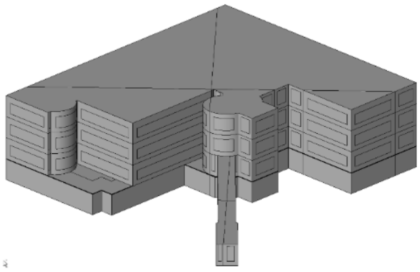
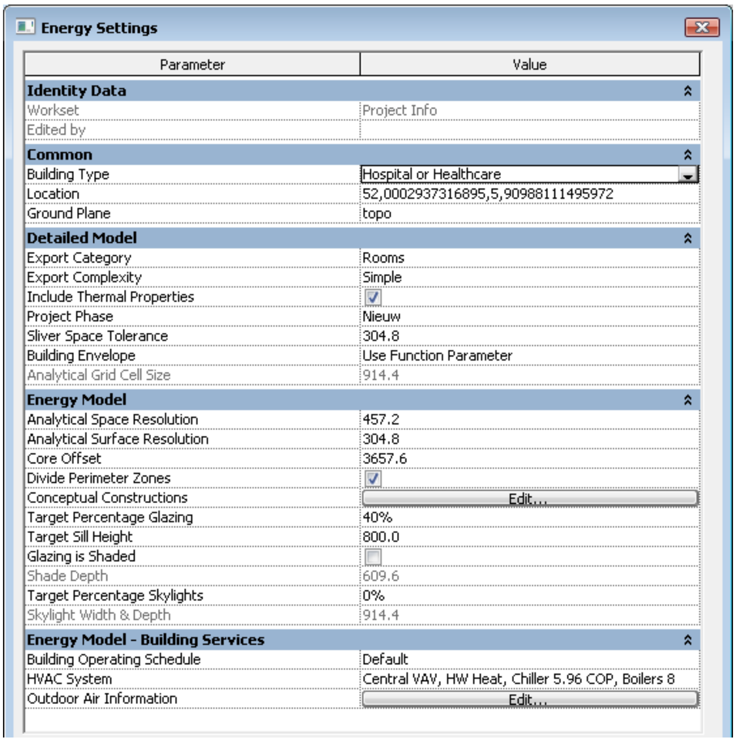


Figure 20: a mass in Revit. Abstract window zones are created based on general glazing percentage.

It is also possible to export the architectural mass model to IFC, although the amount of included energy related data is more limited. Data-flow for every scale level has been graphically summarized in images like Figure 22.

- Data content / topic is represented by a colour
- The small black arrows represent the direction of data-flow (either one- or unidirectional)
- Red Cross means: no data flow.
- Circular black arrows mean: synchronization back and forth



Parameter	Value
Identity Data	
Workset	Project Info
Edited by	
Common	
Building Type	Hospital or Healthcare
Location	52,0002937316895,5,90988111495972
Ground Plane	topo
Detailed Model	
Export Category	Rooms
Export Complexity	Simple
Include Thermal Properties	☑
Project Phase	Nieuw
Sliver Space Tolerance	304.8
Building Envelope	Use Function Parameter
Analytical Grid Cell Size	914.4
Energy Model	
Analytical Space Resolution	457.2
Analytical Surface Resolution	304.8
Core Offset	3657.6
Divide Perimeter Zones	☑
Conceptual Constructions	Edit...
Target Percentage Glazing	40%
Target Sill Height	800.0
Glazing is Shaded	☐
Shade Depth	609.6
Target Percentage Skylights	0%
Skylight Width & Depth	914.4
Energy Model - Building Services	
Building Operating Schedule	Default
HVAC System	Central VAV, HW Heat, Chiller 5.96 COP, Boilers 8
Outdoor Air Information	Edit...

Figure 21: Revit energy settings dialogue. These parameters can be modified in the architectural model and are included in the exported gbXML file for analysis purposes.

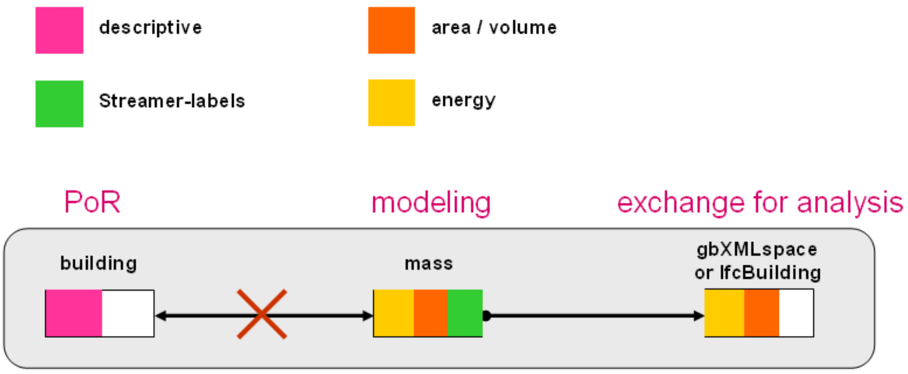


Figure 22: representation of data-flow on building level. Main conclusion: Streamer labels are not attached preserved in the analysis exchange file.

Energy analysis

Computer simulation of building energy consumption is one of important assisted tools in the field of energy efficiency. Engineers can easily design process at any stage of the design of energy-saving evaluation by computer simulation, or test can predict the future or existing buildings energy consumption, diagnostic analysis of building thermal process, so as to optimize the building design, to minimize energy consumption to provide an accurate basis. Just type in the program model of the architect, we can complete in design software, thermal performance, natural light, artificial lighting, sunlight, and economic analysis and understanding the impact of construction on the environment. These results can help the engineers at the design stage compared the advantages and disadvantages of different options to make more energy-efficient choices can be completed in the software design of the thermal performance, natural light, artificial lighting, sunlight, and the economy analysis and understanding of the environmental impact of buildings. In recent years, with the large-scale application and popularization of computer, computer-based simulation software applications are constantly updated with the development of services for promoting green building and sustainable development.

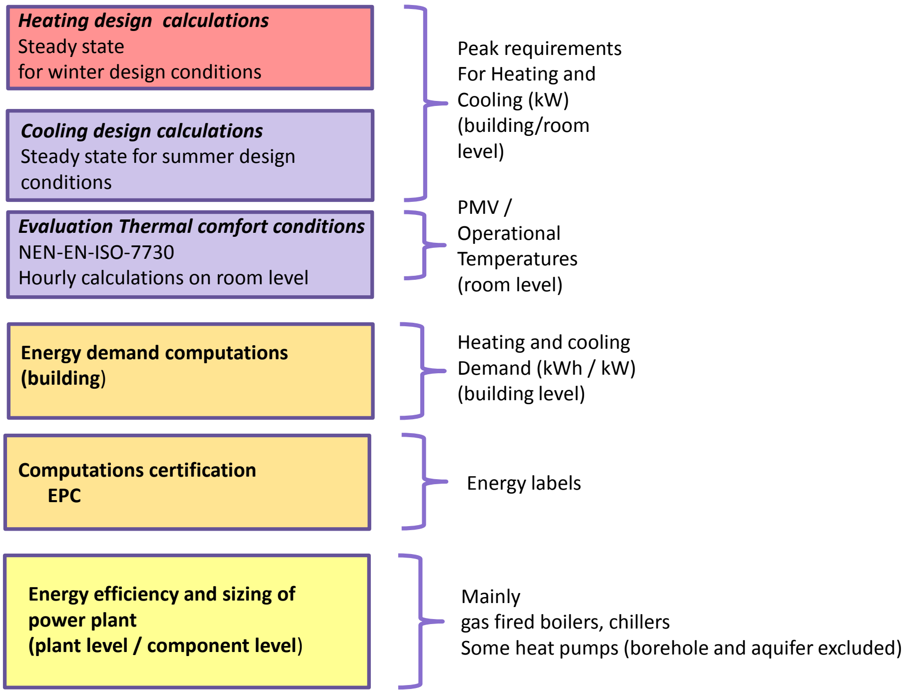


Figure 23: different computing simulations for HVAC engineering

Many European countries have developed their own building energy simulation software, play in the actual use of a larger economic and social benefits. Domestic and foreign applications and analysis of building thermal environment simulation software more, which is more popular and authority are: DOE-2 software, Vabi Elements software, TRNSYS software, ESP-r software, Climate Surface software, and FLUENT software. Most usable in the design phase. See also WP3 for explanation.

In this case we use the commercial design tool Vabi Elements for computing simulations for energy analysis of a 3D-model. Using Vabi Elements is because the strong position with connection to (Dutch) legislation and combine several simulations and computing in one BIM flow as figured above.

Vabi Elements can handle IFC format files as input for computing energy simulations. gbXML files should be converted to IFC formats. Both on building/mass level and department and room level. The workflow process is the same. The only different is the typology of IfcSpace for the different Rooms, Spaces of Areas. Because Rooms, Spaces or Areas must have IFC Class Name 'IfcSpace'.

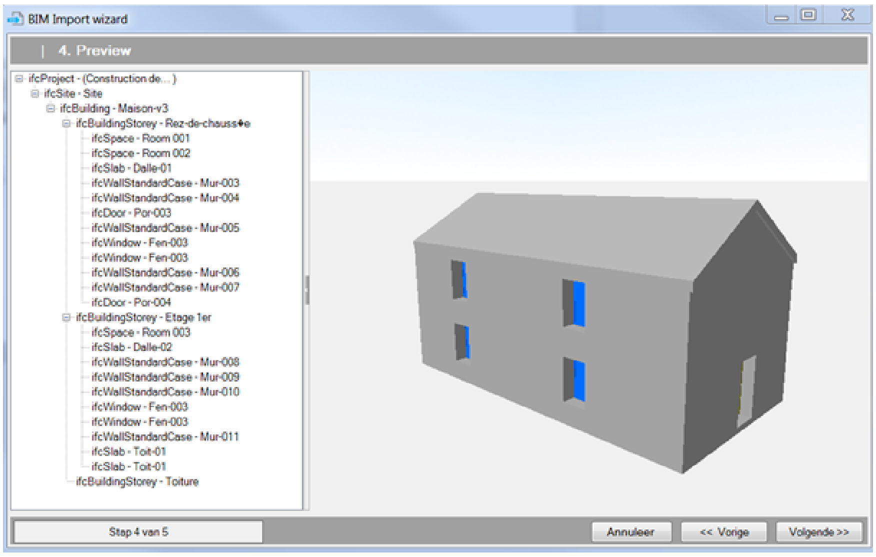
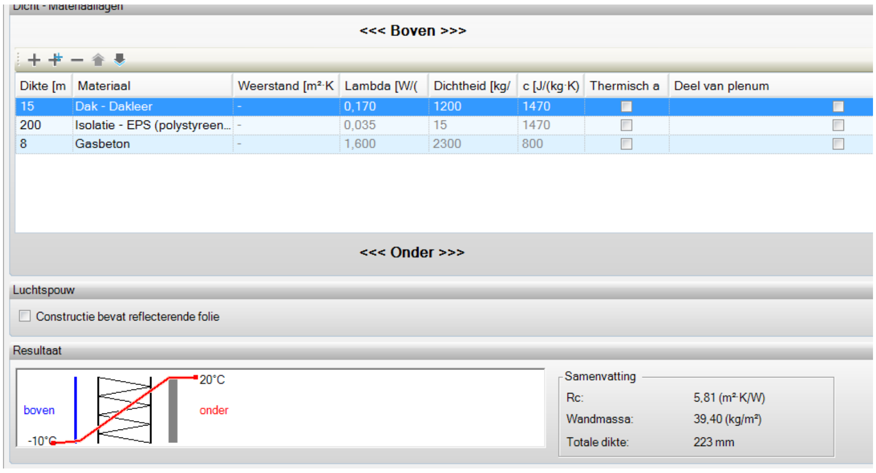


Figure 24: example of input via BIM connect tool for importing IFC file or a Sketchup model.

The import parameters are location of the building, geometric data of facades (included air conditions on both side of the walls), rooms and layer names. The current version of Vabi Elements cannot import further detail information like occupancy and material properties. These parameters should be added manually.



Dikte [m	Materiaal	Weerstand [m²·K	Lambda [W/(	Dichtheid [kg/	c [J/(kg·K)	Thermisch a	Deel van plenum
15	Dak - Dakleer	-	0,170	1200	1470	☐	☐
200	Isolatie - EPS (polystyreen...	-	0,035	15	1470	☐	☐
8	Gasbeton	-	1,600	2300	800	☐	☐

☐ Constructie bevat reflecterende folie

Samenvatting

Rc:	5,81 (m²·K/W)
Wandmassa:	39,40 (kg/m²)
Totale dikte:	223 mm

Figure 25: example of manually adding material properties to a wall

After doing that computing simulation can be done to analyse the energy usage (gas and or electricity), design cooling load for design heating components, and compute the design indoor temperature. Also creating an energy label is possible. The export of Vabi Elements is different types of energy loss and indoor climate design parameters in IFC file or gbXML file. This can be done on the scale level of the whole building, a department and room level.

The data-flow for energy analysis computing is figured below.

- PoR is Program of Requirement, Modelling is the architectural design. Energy analysis is computed by simulation for energy analysis.

The energy analysis in can handle both import and export, Streamer labels, area/volume design parameters and energy calculations.

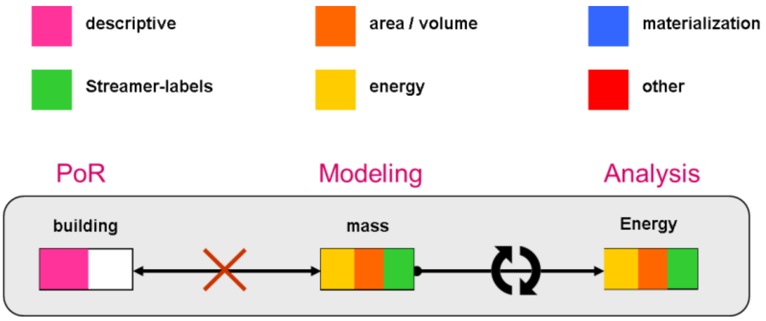
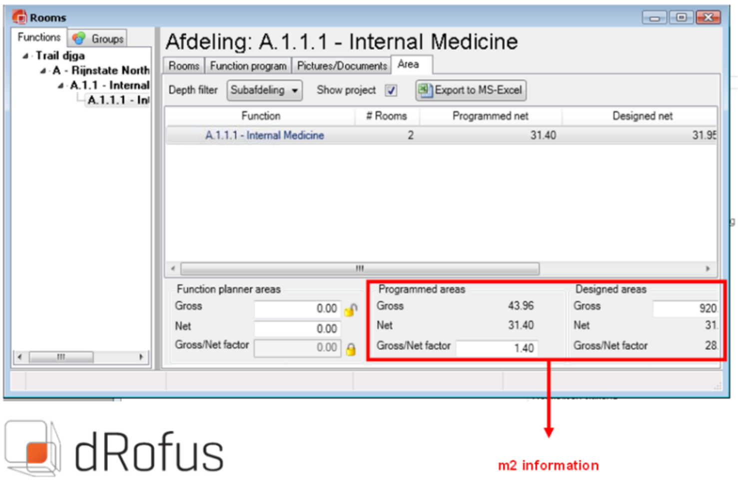


Figure 26: data-flow energy analysis computing

3.2.3 Functional area (zone) scale level

Usually a functional area is a collection of rooms belonging to the same department, which also includes circulation spaces. When small technical spaces and wall thicknesses are also included, the functional area is a Gross Floor Area (GFA). The size of a Functional area can be determined by adding the surfaces of all rooms belonging to the functional area and then either adding an allowance for internal walls or by multiplying this area with a gross/net factor. This factor is different for every type of functional area and is largely dependent on the layout of the floor plan. A screenshot from dRofus (Figure 27) shows the information related to the functional area “Internal medicine”. Information concerning size is highlighted in the red box. The Gross/net factor can be customized for every functional area



Afdeling: A.1.1.1 - Internal Medicine

Depth filter: Subafdeling

Show project ☑

Function	# Rooms	Programmed net	Designed net
A.1.1.1 - Internal Medicine	2	31.40	31.95

Function planner areas

Gross 0.00

Net 0.00

Gross/Net factor 0.00

Programmed areas

Gross 43.96

Net 31.40

Gross/Net factor 1.40

Designed areas

Gross 920

Net 31

Gross/Net factor 28

Figure 27: Screenshot from dRofus showing the information related to the functional area

The functional area in the PoR can be synchronized to an “area” in the modelling environment. This connection allows the requirements to be compared to the actual model. In the modeling environment, custom parameters (such as labels) can be added and visualized by colour schemes. This visualization assists in validation for consistency. When exporting to IFC, these custom parameters are preserved.

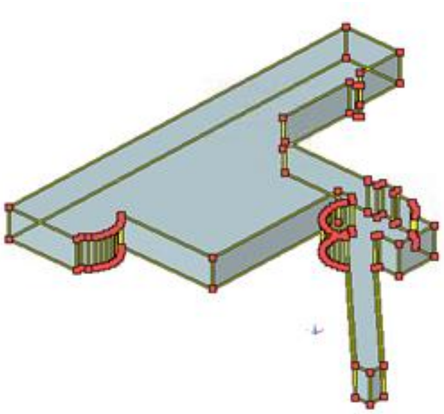


Figure 28: representation of a functional area in an IFC file as a spatial element.

Main conclusion is that the Streamer labels are preserved in the IFC model, but it is not yet possible to transfer them from the PoR to the modelling environment (Figure 29)

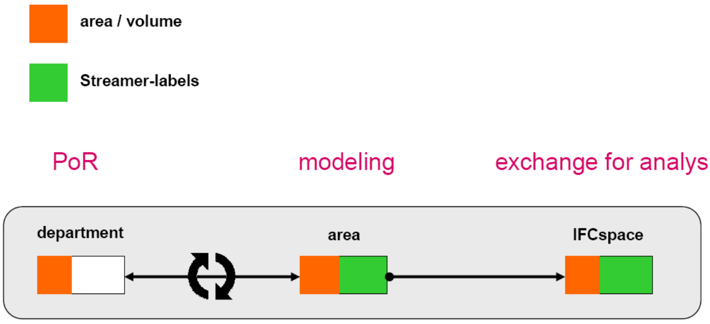


Figure 29: Data-flow on functional area level.

Energy analysis

Simulating the energy usage on area level is just the same as building scale level. The same parameters as input are necessary. The workflow process is the same too. The only different is the typology of IfcSpace for the different levels Rooms, Spaces of Areas. Because Rooms, Spaces or Areas must have IFC Class Name 'IfcSpace'. The area/volume and Streamer-labels who are included in the IfcSpace file can be used in the energy-simulating tool.

3.2.4 Room scale level

In the PoR, the room is the main information carrier, since most requirements are described on room-level. A room could contain information about:

- labels
- activities
- daylight / view outside
- indoor climate
- lighting
- acoustics

All this information can be synchronized between the PoR and the model. Every parameter can be visualized, just like on the functional area scale level:

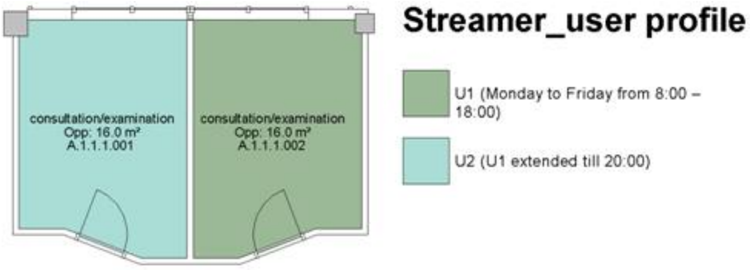


Figure 30: Floor plan fragment in which each user profile labels value is visualized by a unique colour.

In the example above, the colour scheme tells us that two rooms with different user profile values have been placed next to each other. This can either be accepted or solved (the designer might relocate one of the rooms, or the user will change the user profile of the rooms in the PoR to better suit the building layout). When exporting to IFC, all information from the PoR and the model is preserved. The main conclusion is that all data can be transferred between the modelling and the exchange file (see Figure 31).

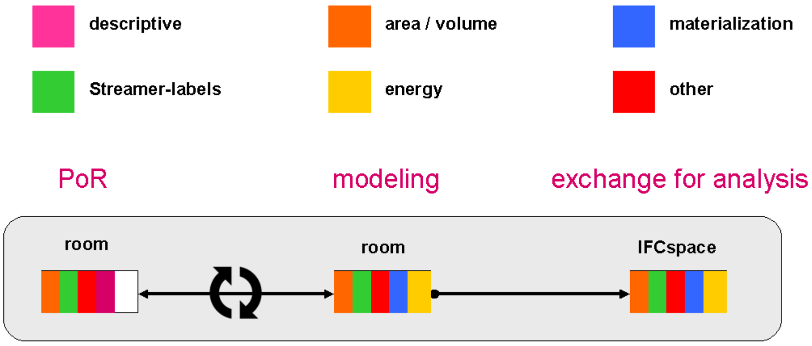
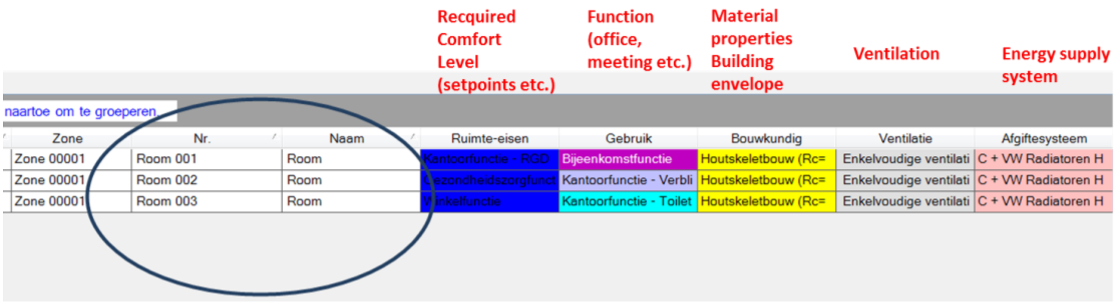


Figure 31: data-flow on room level.

Energy analysis

On room level, the energy simulation tool, can import the IfcSpace format file, including the Streamer labels. Based on this Streamer labels, it’s necessary to prepare a library of specification for each parameter, to be clear what is meant by a Streamer label. For example the design indoor temperature in an office or a hot floor is different. This should be incorporate in the PoR as a user profile.



Zone	Nr.	Naam	Ruimte-eisen	Gebruik	Bouwkundig	Ventilatie	Afgiftesysteem
Zone 00001	Room 001	Room	Kantoorfunctie - RGD	Bijeenkomstfunctie	Houtskeletbouw (Rc=	Enkelvoudige ventilati	C + VW Radiatoren H
Zone 00001	Room 002	Room	Gezondheidszorgfunct	Kantoorfunctie - Verbli	Houtskeletbouw (Rc=	Enkelvoudige ventilati	C + VW Radiatoren H
Zone 00001	Room 003	Room	Winkelfunctie	Kantoorfunctie - Toilet	Houtskeletbouw (Rc=	Enkelvoudige ventilati	C + VW Radiatoren H

Figure 32: rooms and the required comfort level, function and properties, based on the Streamer-layer input.

3.2.5 Component scale level

In the modelling environment, a lot of information can be attached to objects that are somehow related to the energy consumption of the building. It is important to note that this implies that the architect, who is responsible for modelling the wall, is also the one who supplies the information about the analytical properties of the wall. This is not an ideal situation, because this should be the responsibility of the building services advisor.

In a BIM authoring tool, al lot of information can be added to the wall type:

- Heat transfer coefficient
- Thermal resistance
- Thermal mass
- Absorbance
- Roughness

Also, information about the materials associated with this wall can be provided:

- Thermal conductivity
- Specific heat
- Density
- Emissivity
- Permeability
- Porosity
- Reflectivity
- Electrical resistivity

Going in further details: for heating or cooling energy calculation, it is only necessary to know the geometry and thermal conductivity of the walls. More details as summed up above are not relevant for energy analysis, but very relevant for HVAC designing. These parameters are typically design parameters for the architect. However, inspection of the same wall after export to IFC reveals only information attached to the wall type can be included.

3.2.6 System approach

The physical equivalent of this Zoning approach is the Systems approach. Both the building systems (such as the frame, or enclosing walls) and the distribution systems (such as heating or lighting) can be characterised by their performance requirements prior to the selection of a specific solution and prior to the selection of specific components. Whilst the PoR will focus on the departmental requirements, there may be specific system requirements (such as medical gasses) and a description of the solution should include a schedule of all the major Systems envisaged.

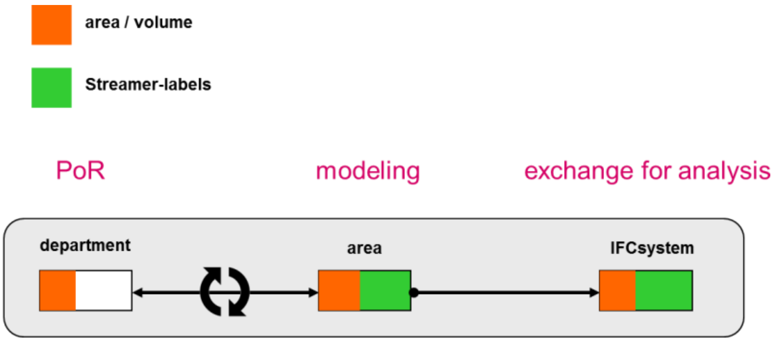
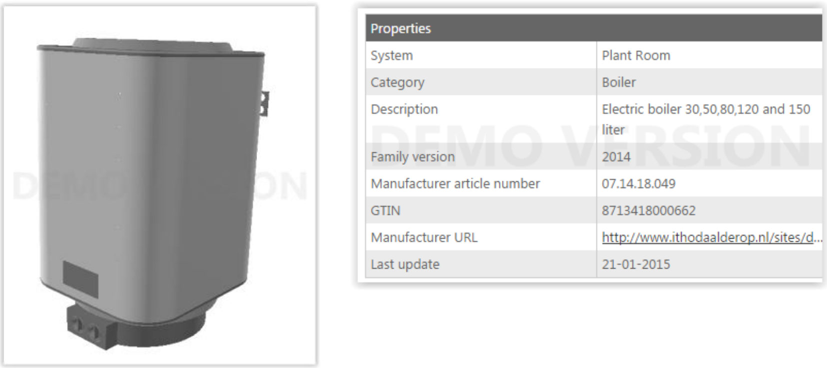


Figure 33: data-flow on system level

3.2.7 Elements approach

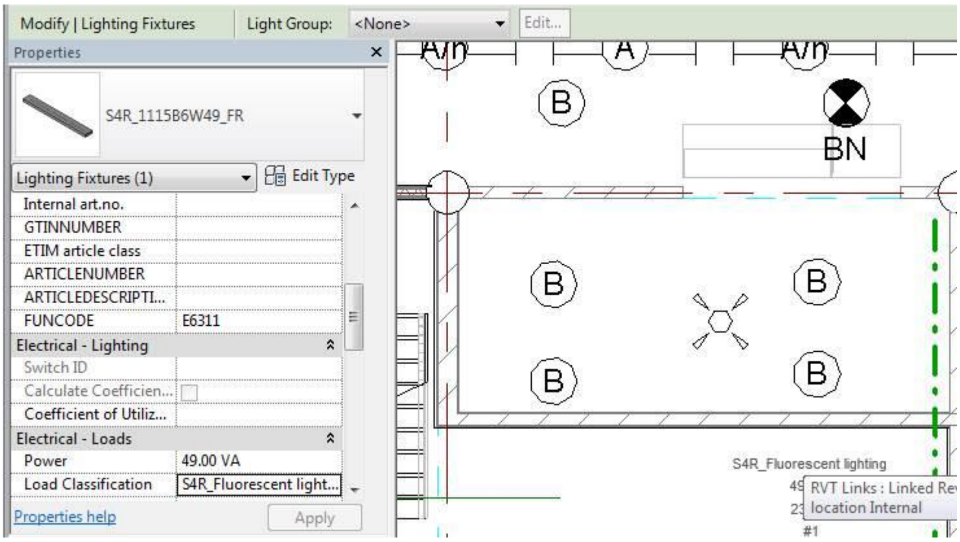
The physical equivalent of this spatial approach is the elements approach. Both the building elements (such as the walls or windows) and the major distribution elements (such as air handling units and pumps) can be characterised by their performance requirements prior to the selection of specific components and geometry. These major Elements may serve as proxies for their Systems, as the connections and distribution networks may be constant for a given building shape. The HVAC manufacturing sector provide downloadable BIM '3D blocks' that can be loaded into a model. The dimensionally accurate models do have standard models and accessory combinations.



Properties	
System	Plant Room
Category	Boiler
Description	Electric boiler 30,50,80,120 and 150 liter
Family version	2014
Manufacturer article number	07.14.18.049
GTIN	8713418000662
Manufacturer URL	http://www.ithodaalderop.nl/sites/d...
Last update	21-01-2015

Figure 34: example of a 3D Element boiler, both geometric model and added properties.

In addition, design software for a lighting plan (like RELUX and DIALux) allow lighting designers to import BIM models directly into their programs and run lighting calculations on the areas that they want (Figure 35). The design software recognises the room surface finishes that will be integral to the BIM model.



S4R_1115B6W49_FR

Lighting Fixtures (1)

Internal art.no.	
GTINNUMBER	
ETIM article class	
ARTICLENUMBER	
ARTICLEDESCRIPTI...	
FUNCODE	E6311
Electrical - Lighting	
Switch ID	
Calculate Coefficien...	☐
Coefficient of Utiliz...	
Electrical - Loads	
Power	49.00 VA
Load Classification	S4R_Fluorescent light...

S4R_Fluorescent lighting

RVT Links : Linked Re

location Internal

Figure 35: example of a lighting plan, including properties and electrical power load of an armature.

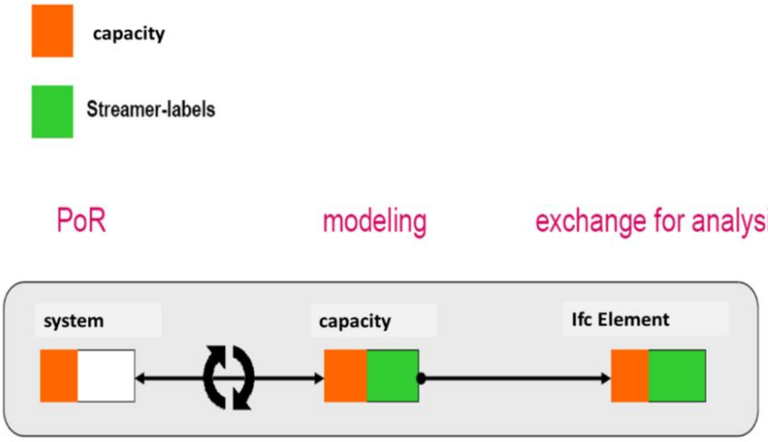


Figure 36: data-flow on element level.

3.3 Information exchange and developments in Streamer

The Streamer approach is expected to provide design configuration/validation specifically aimed at reducing energy consumption in hospitals, and bring the current state of the art one step further.

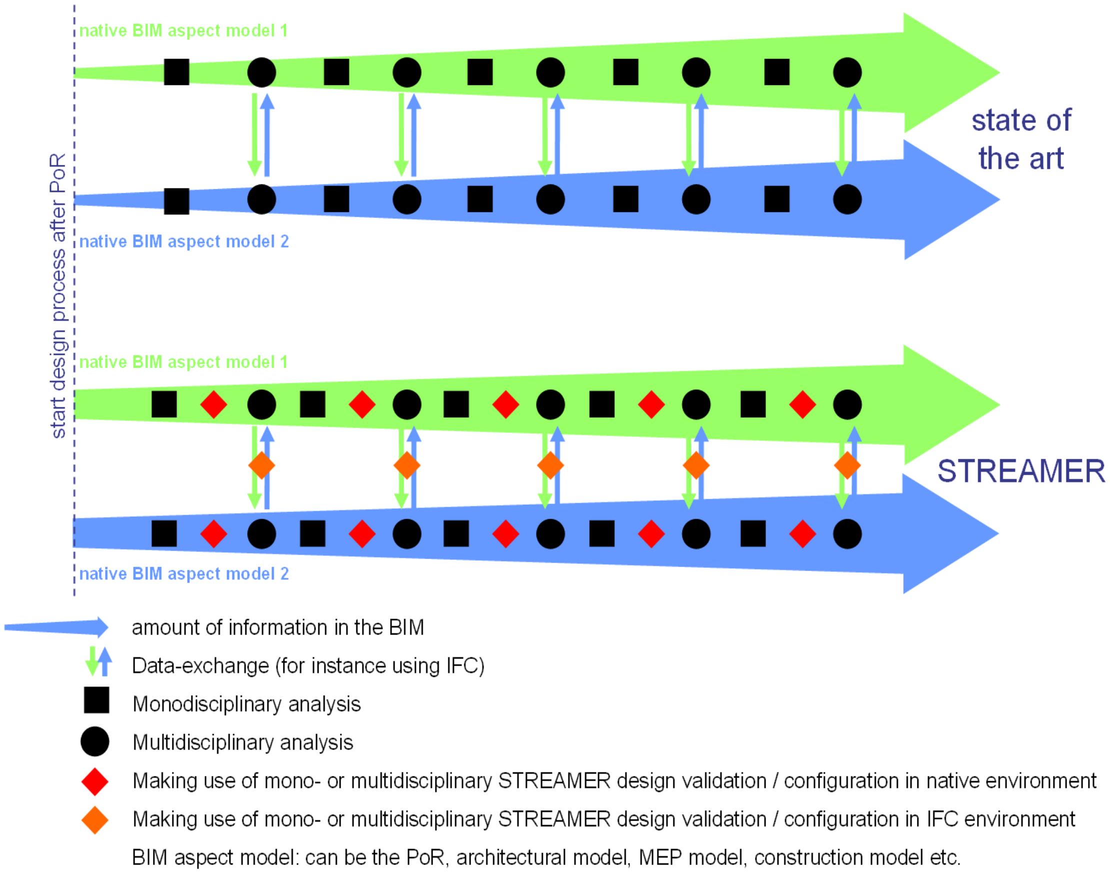


Figure 37: illustration of main differences between the current state of art and the Streamer process.

When a clash control is being performed on a single model, this is a mono disciplinary validation. An example of multidisciplinary validation is a clash control between the structural and architectural model. Revit is an example of a native environment, as opposed to an IFC environment, which is more accessible (See Figure 37).

Prerequisites for both the state of the art and Streamer process as described in the image:

- All advisors use BIM modelling software and their models can be exchanged using IFC.
- All advisors (structural, MEP, architect) can link the other aspect models (IFC or native) into his own native software application (e.g. Revit, ArchiCAD, DDS-cad, etc.).

4. Conclusions

Previous chapters reflect the current state of the art in using ontologies in the AEC industry and already started to identify and specify knowledge for Streamer use cases. This chapter shortly recaps the current situation in the AEC industry. It explains advantages, challenges and possible barriers for using and extending that technology. It then discusses potential use cases and required extensions that fit to the overall goal of the Streamer project. And it describes first prototype implementations and findings that are used to further detail research directions and developments as finally concluded in chapter 5.

4.1 Conclusions about the state-of-the-art

As discussed in the previous chapters, ontologies can easily cover a very broad spectrum of research issues. Approaching the topic from Semantic Web definitions the review can be much more focused, in particular looking at the use of OWL/RDF specifications and related tools. A main difference of Semantic Web (OWL) ontologies compared to traditional modelling approaches is the open world assumption it resembles. If something is not explicitly claimed, it can still be true where other ontologies presume it will be false (or incorrect). This open world assumption makes these ontologies more flexible and extendable. The ability to query OWL via SPARQL is another advantage and reason to use it as well as the maturity of tools.

A couple of developments within the AEC industry like for instance the work on concept libraries or the translation of the IFC/BIM standard to ifcOWL make this research direction particular interesting for Streamer developments. The current effort to agree on an ifcOWL representation will for instance enable to bridge the gap between existing BIM-based engineering applications and novel ontology-based design solutions. Models defined in IFC by traditional CAAD tools can be transformed to the ifcOWL ontology to be further processed and evaluated. For example, via SPARQL queries the ifcOWL ontology can then be validated against restrictions and requirements. Nevertheless Streamer does not focus on BIM only, it also reflects to GIS data to describe the holistic building. This BIM and GIS data will originate from various sources (web, CAD tools, analysis tools, etc.), which are based on different knowledge representations that can contain similar information (redundancy). The classical approach would be to combine the information in a single, redundant free knowledge representation, which would require data transformations and thus is expected to lose knowledge due to semantic differences. Besides the loss of information, existing tools used in Streamer would need adoption to support this knowledge representation, which however is not feasible due to limited development resources. Therefore Streamer is expected to use multiple standards in collaboration. Here, the Linked (Open) Data approach proposed by the Semantic Web community can provide solutions to be followed to identify overlapping content and for managing relationships.

Dealing with Semantic Web ontologies three main challenges and barriers have to be mentioned.

- Semantic web technology is not an answer to all questions, information exchange to enable data flow between applications is still a main focus and is best realized by existing IFC/CityGML standards and technologies. Therefore the focus has to be on a hybrid approach, use and further enhance model based information exchange while complementing solutions with Linked Open Data and semantic web technologies.

- AEC-specific ontologies are still very rare; if available they are mostly derived from other standards and thus have to be transferred to RDF/OWL in order to fit into the OWL tool environment. Accordingly, there is very few AEC-specific knowledge encoded in OWL yet.

- Design tools do not support the Sematic Web technology, thus they have to be extended or redesigned. Available tools using semantic web mainly cover generic modelling, reasoning and data management tasks. They typically require special skills and background knowledge in Semantic Web technology due to its generic nature and not operable by AEC related specialist.

When approaching the topic of ontologies from a broader perspective taking into account the various standardization efforts towards BIM and GIS (not semantic ontologies) as well as related developments for capturing knowledge about the design process and collaboration, it becomes obvious that a lot of results in terms of ontological commitments and open knowledge has already been achieved. Also, many domain-specific tools provide support for these agreements. Thus, rather than to switch to a new technology it is proposed to follow a hybrid approach where both solutions (Semantic Web ontologies and existing BIM/GIS standards and solutions) can co-exist in order to provide better design services.

In general, using multiple standards means to align the information contained in different models, if not, redundancy can turn to discrepancies. In order to align information, a change should affect (update) all other data models. This can be done manually, where a user is responsible updating all data models. However this requires commitment of the users following a guideline of actions to take when updating parts. The better would be an automated system where a user can send its update to, which will automatically update all relevant data models. The next chapters discuss main proposals and results from prototype developments.

4.2 Potential use cases

Previous chapters have shown that substantial knowledge is already encoded using open standards. A major technology pull is coming from BIM developments trying to integrate as much information as possible about a particular building into a coherent database. Most of that knowledge is still on the level of a data structure using either XML schema or similar database definitions. However, they can be regarded as an important ontological commitment that provide a sound basis to improve communication between domain experts as well as to offer better services like for instance different kinds of energy analysis, other simulations or data checks. Such data structures become even more interesting as they are supported by a couple of CAD authoring tools that are already used in practice. Also, by looking at the development resources that have been spent so far in BIM developments we want to make use and extend that knowledge.

As already mentioned in our initial problem statement and as proven in our state of the art analysis additional efforts are necessary to improve BIM data management and to interconnect BIM with other standards like for instance various classification systems and other norms, local reference structures or dictionaries. The following use cases related to ontological specifications are of interest for further developments in Streamer:

1. improve BIM information management
   (e.g. by annotations attached to BIM data available as IFC, gbXML or other data format)
2. interlink various data sources
   (e.g. making use of the LOD approach by transforming (parts of) BIM data to a RDF graph and publish it on the web for referencing)
3. encode additional knowledge
   (e.g. by adding constraints to check design data or further parameterize design solutions)

4.3 Early prototype development

Based on initial proposals to support Streamer use cases two trial implementations have been started to run first basic tests in order to decide about further development steps within Task 5.1. Both implementations are based on earlier solutions from Streamer partners and are described below.

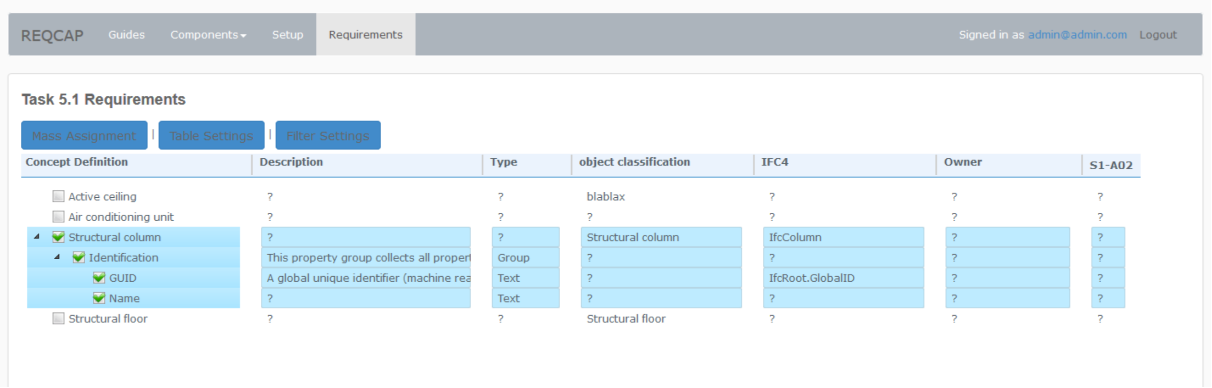
4.3.1 Requirements Management Database

A trial implementation done by AEC3 is targeting use cases (1) and (3) as described in chapter 4.2. A web-based requirements management solution supports capturing exchange requirements in a semi-formal representation and is addressing a couple of requirements management issues. This part of the solution is related to the IDM method (see chapter 2.2.1), but without dealing with process maps. Instead, it enables to capture domain requirements in a flexible hierarchical structure. An example is shown in Figure 38. This kind of specification is related to modelling tools like TopBraidComposer or Protégé, but highly specialized in order to fulfil the needs of requirement definitions. The tool for instance enables defining reusable components like objects or properties that can easily be configured to requirements, which then can be linked to data exchange points as identified in a process map. It is also possible to define links to other structures like classification systems, data format or languages. For instance, an object or property can be linked to the buildingSMART Data Dictionary that holds a full concept definition and may offers translation to other languages. This mechanism is also used to hold mvdXML specifications, which essentially enables to translate requirements (from a semi-formal definition of domain experts) to the IFC data structure.

In this way, the Requirements Management Database makes the digital ‘Plan of Work’ explicit in different ways. It can export structured rules of spreadsheets for comment and review offline, to PDF documents to form contractual annexes and as mvdXML for automated checking of deliverables. mvdXML can be used for checking by several applications e.g.:

a. IfcDoc and Constructivity viewer
b. Open BIM server
c. AEC3 RMD checking (based on UNN Xbim Xplorer toolkit – see Figure 39).

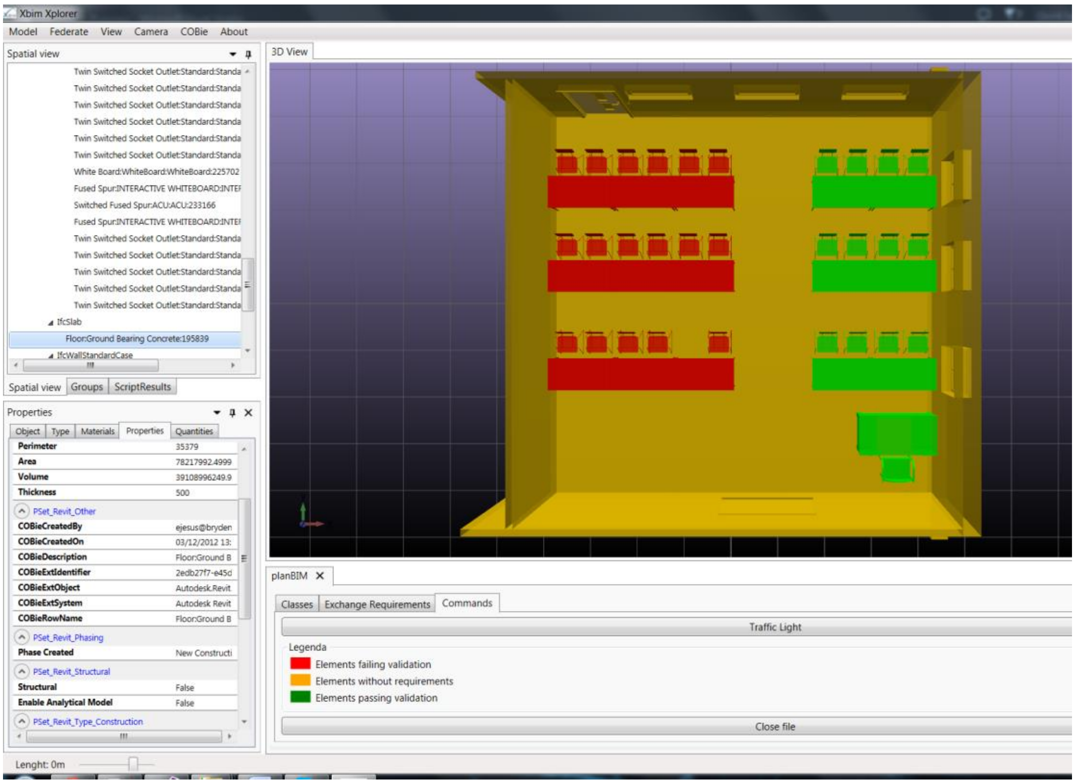
While the concept has been proven with the shown development tool it is still in an early stage. A couple of improvements are currently discussed such as better translation to mvdXML or enhanced support of requirement settings. Also, integration of other data sources like the buildingSMART Data Dictionary or classification systems is discussed.



Task 5.1 Requirements

Concept Definition	Description	Type	object classification	IFC4	Owner	S1-A02
☐ Active ceiling	?	?	blablax	?	?	?
☐ Air conditioning unit	?	?	?	?	?	?
☑ Structural column	?	?	Structural column	IfcColumn	?	?
☑ Identification	This property group collects all propert	Group	?	?	?	?
☑ GUID	A global unique identifier (machine rea	Text	?	IfcRoot.GlobalID	?	?
☑ Name	?	Text	?	?	?	?
☐ Structural floor	?	?	Structural floor	?	?	?

Figure 38: Screenshot of the requirements management tool and the hierarchical structure of requirements



Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
White Board:WhiteBoard:WhiteBoard:225702
Fused Spur:INTERACTIVE WHITEBOARD:INTEI
Switched Fused Spur:ACU:ACU:233166
Fused Spur:INTERACTIVE WHITEBOARD:INTEI
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
Twin Switched Socket Outlet:Standard:Standa
IfcSlab
Floor:Ground Bearing Concrete:195839
IfcWallStandardCase

Perimeter	35379
Area	78217992.4999
Volume	39108996249.9
Thickness	500
PSet_Revit_Other	
COBieCreatedBy	ejesus@bryden
COBieCreatedOn	03/12/2012 13:
COBieDescription	Floor:Ground B
COBieExtIdentifier	2edb27f7-e45d
COBieExtObject	Autodesk.Revit
COBieExtSystem	Autodesk Revit
COBieRowName	Floor:Ground B
PSet_Revit_Phasing	
Phase Created	New Constructi
PSet_Revit_Structural	
Structural	False
Enable Analytical Model	False
PSet_Revit_Type_Construction	

Lenght: 0m

Legenda
🟥 Elements failing validation
🟧 Elements without requirements
🟩 Elements passing validation

Figure 39: IFC model checking using XBIM Xplorer based on mvdXML

4.3.2 Prototypical ifcOWL import

IFC-Explorer allows the display of different formats like IFC or CityGML. To facilitate the integration of OWL Ontologies with IFC-Explorer a prototype was developed that is able to load and display an OWL Ontology representing an IFC file converted from IFC to OWL. The implementation of OWL in IFC-Explorer is a first step to be able to display several different Ontologies described in OWL in one document in IFC-Explorer, e.g. data from a CityGML-OWL, IFC-OWL or an internal Streamer OWL.

In an early prototype example a Reasoner was used to map two different ontologies, one meant for displaying of 3D data and an IFC-OWL-representation.

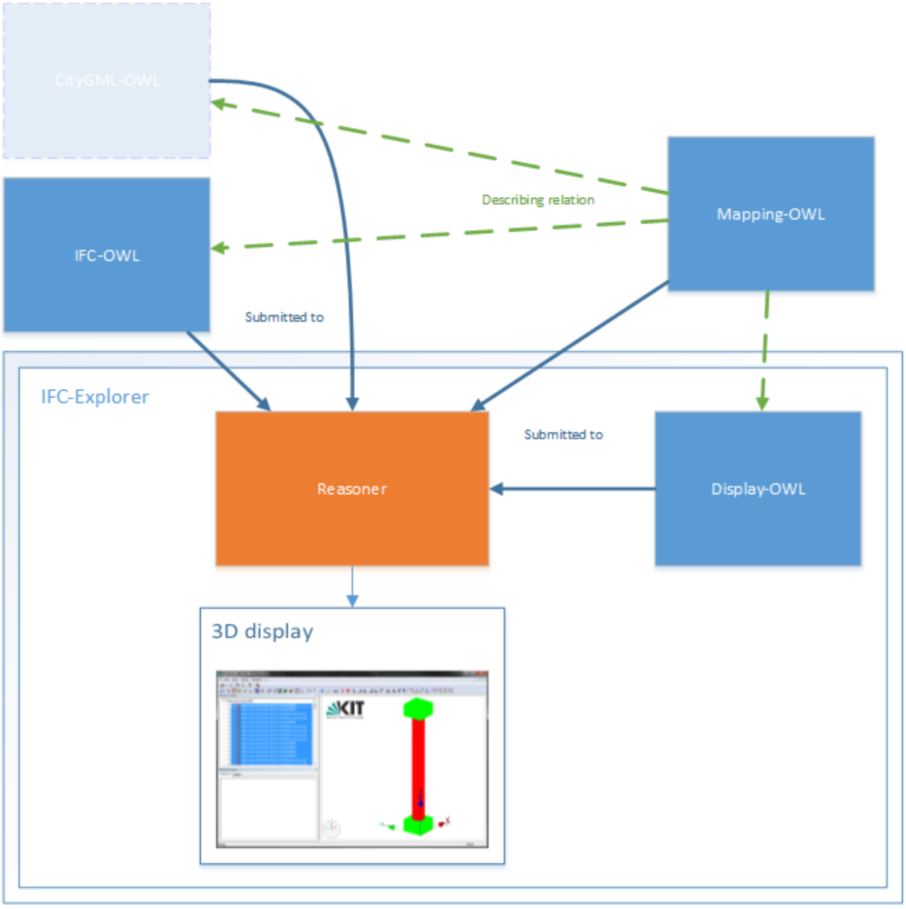


Figure 40: How to display a mapped OWL file

Several steps are necessary to achieve this:

1. An IFC model needs to be converted into an OWL representation (IFC-OWL). Therefore first the EXPRESS Schema for the IFC file has to be converted into an IFC-OWL schema ontology.
2. Then the IFC model has to be transformed into the matching IFC-OWL Model Ontology, referencing the aforementioned IFC-OWL Schema Ontology.
3. An internal Display Ontology needs to be defined in OWL. This Ontology is understood by IFC-Explorer which is able to display a model described in this Display Ontology.
4. A Mapping Ontology is required to be defined in OWL, which describes which classes and properties of the IFC-OWL Ontologies and the Display Ontology are equivalent.

The relationship between reasoner and the different required Ontologies is shown in Figure 40. A reasoner can tell, through the relations described in the Mapping Ontology, which Display Ontology element to use for which class in the IFC-OWL ontology (or any other ontology) and the element can then be displayed.

Converting IFC and EXPRESS to OWL is a difficult task. EXPRESS e.g. does not differentiate between object properties and datatype properties like OWL does (e.g. SELECT types from EXPRESS can mix what would be ‘ObjectProperties’ and ‘DatatypeProperties’ in OWL). Also there is to decide which IFC model elements result in a ‘NamedIndividual’ in OWL. The solution to how this is implemented depends on the converter. The implemented prototype allows mapping of two IFC Elements, IfcBlock and IfcRightCircularCylinder to an internal Display Ontology. Those two elements can then be displayed. The used IFC Ontology is custom generated for this use case from the needed EXPRESS schema and an IFC model.

The only freely available reasoner which can be integrated into a C++ program (the language IFC-Explorer is written in) is FaCT++. OWLCPP was used to submit the Ontology to the Reasoner. The existing IFC-OWL converter IFC-to-RDF seems not to be able to generate OWL which can be loaded by FaCT++ and OWLCPP because ‘ObjectProperties’ and ‘DatatypeProperties’ are mixed which results in an error from FaCT++.

The conclusion from this prototype implementation supporting IFC-OWL is that there are several drawbacks when comparing it with using IFC in its STEP or XML format directly. The tested IFC-OWL Ontologies still need a lot of work to be implementable and seem to be more in a proof-of-concept state. Software available for conversion is rare, especially with the goal to integrate it into other tools. Opposing to that, IFC in its STEP or XML representation has several mature tools available. Therefore a hybrid approach would be the better option. References from OWL into IFC documents could be either by using an IFC UUID or by marking IFC elements with custom IFC properties.

5. Recommendation

Previous chapters cover a broad spectrum of topics related to ontology developments discussing yet available (open) ontological commitments for design data and design processes, relevant tools for modelling and data management as well as first steps towards identification of relevant Streamer knowledge in particular for the Programme of Requirements use case. It has been shown that Streamer can already benefit from many developments, or vice-versa that it cannot be goal to remodel that knowledge, and therefore that a hybrid approach that combines existing solutions with new Semantic Web technologies would be a reasonable integration solution. This means to rely on existing data exchange standards such as IFC and CityGML, which is seen as a big advantage because Streamer will be able to make use of a very rich AEC toolset. Beneficial extensions have been identified as potential use cases and first prototype developments have been presented as a proof of concepts. This final chapter describes our conclusions and the direction of further developments within Streamer task 5.1 and also shows the relationships to other work within Streamer.

5.1 Conclusions and further work within Streamer

Based on the presented state-of-the-art review a hybrid approach is suggested that extends current BIM/GIS developments. Today, a main challenge is information management and quality control that is basically checking if provided information fulfils expected requirements and constraints. These requirements can be separated into two kinds:

- Exchange requirements identifying the necessary data for a specific purpose (tool, phase).
- Project requirements combination of regulations (country depending), tacit knowledge and end-user (PoR).

Checking requirements is a very knowledge intensive task, which is still done mostly manually with limited tool support. In general, different types of checking activities can be distinguished depending on the kind of requirements or constraints that shall be applied to a dataset. The challenge is to capture and encode that knowledge so that it is available for automatic checking. Furthermore such encoded knowledge shall be open, reusable and maintainable.

Two developments related to IFC are of special interest for further research in task 5.1:

- IDM/MVD, in particular mvdXML that enables to encode checkable exchange requirements
- ifcOWL that enables Semantic Web technologies for reasoning and validating a model against project requirements.

Both directions have already been tested with prototype implementations. While IDM/MVD is essentially specifying the use of IFC and is in-line with buildingSMART standardization efforts, ifcOWL is a semantic-web enabled representation format for IFC data. They both provide a basis for encoding additional knowledge that supports BIM information management and quality control.

The specific challenge in using IDM/MVD is to capture project requirements in a semi-formal, but still flexible and user-friendly way that can be linked to the IFC data structure via mvdXML templates. The goal will be a solution that is based on a predefined set of concepts that can be easily configured to requirements as for instance defined in chapter 3. The main use case (or type of quality control) is to check if all required information is contained within an IFC dataset or if something is missing. Such checks typically do not require very deep engineering knowledge in terms of complex algorithms as needed for instance for checking escape routes or other regulations, but they enable managing the information flow and are seen as a basis for further consistency checks and other kinds of quality control. We expect that such checks will be demanded in near future as it will help to sort-out many issues related data exchange.

The specific challenges for further work in task 5.1 are:

- identify typical data requirements – to be done by domain experts for the selected processes
- capture the data requirements in a semi-formal (re-usable) structure (requirements ontology)
- provide mapping definitions to IFC based on mvdXML templates – to be done by IFC experts
- configure those definitions to exchange requirements that are relevant for specific tasks
- export configured requirements as checkable mvdXML – to be implemented in the requirements management tool
- improve and extend the mvdXML checking tool – as plug-in for the BIM server
- provide reporting functionality about identified issues – to be exported as BCF

Following this solution approach we also expect to identify shortcomings for the applicability of mvdXML. This may relate to the expressiveness and clarity of the used rule grammar, the configuration approach and the level of reusability. This may lead to extension approaches for mvdXML to be discussed within buildingSMART. Also, a comparison to OWL-based solutions (e.g. based on ifcOWL or CMO) shall show potential alternatives using Semantic Web approaches. Challenges using ifcOWL enabling Semantic web technologies for reasoning are in the field of the knowledge representation. The translation of IFC-EXPRESS towards ifcOWL is complex and has to be proven first. Besides this step the same goals exist regarding modelling the requirements in a flexible and user-friendly way, compared to IDM/MVD method. One advantage of this method will be the availability of existing reasoners taking care of the actual validation of the model against the requirements.

5.2 Relationship to other work in Streamer

Task 5.1 contributes to the overall goal of Streamer by working on solutions for better information management. Besides the knowledge representation developments as described in chapter 5.1, better information management requires an overview of how Streamer relevant applications and servers cooperate. Such overview is given in Figure 41, the overall Streamer architecture. This overview uses a PLM as a central information manager, which is described in the DoW and intended for maintaining the correct information (per version) within data models. The PLM perfectly fulfils the need for aligning the data sources (mentioned in chapter 4.1), requiring the support of all used data models. In the overview the PLM is represented by 3 separated parts:

- PLM application,
- Streamer BUS
- PLM metadata server.

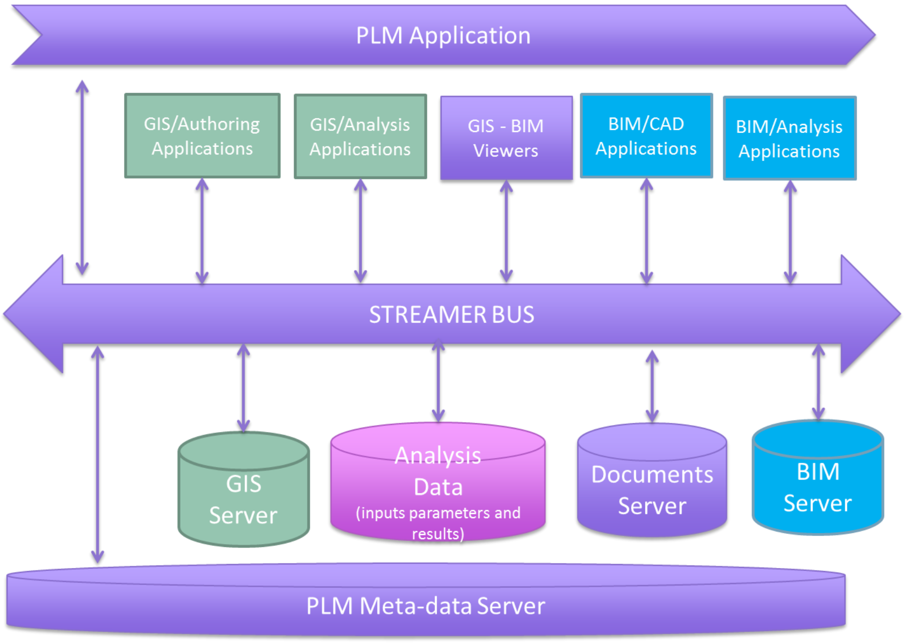


Figure 41 overall Streamer architecture, showing connections between used applications and servers

From the T5.1 point of view the most interesting part of the overall Streamer architecture is the BUS, which works as intermediator in the information management process. The BUS connects applications to process and servers holding the holistic building design. The arrows in the Streamer architecture represent interfaces (API's) and can be restricted to relevant data (exchange requirements) by using IDM/MVD or ifcOWL and Semantic Web technology, as described in the previous chapter. Naturally such an architecture has dependencies with other tasks and work packages. These dependencies are described in the following table:

Table 4 task dependencies of T5.1

WP/Task	**Input** **what is used by T5.1**	**Output** **what is used from T5.1**
Task 1.1	Building typology definitions	
Task 2.1	Overview of knowledge to be represented for the technical equipment (MEP)	
Task 2.2	Overview of knowledge to be represented for the building envelope	
Task 2.3	Overview of knowledge to be represented to connect neighbourhood energy systems.	
Task 3.2	List of usable knowledge representation formats. Information needs to perform energy performance assessment	Energy performance assessment related exchange requirements (in mvdXML or other agreed format)
Task 3.3	Information needs to perform MCA	mvdXML specifications of exchange requirements used for MCA

WP/Task	**Input** **what is used by T5.1**	**Output** **what is used from T5.1**
Task 4.2	Tacit knowledge of the building operator and occupants to be represented.	
Task 5.2		List of to be supported interfaces (knowledge representations)
Task 5.3		Knowledge representation format for not yet representable information
Task 6.1		mvdXML specifications of exchange requirements used for model checking
Task 6.2	Overview of knowledge to be represented for energy simulation and relevant other aspects.	mvdXML specifications of exchange requirements used for energy simulation
WP7		Process definition to clarify use of PoR in pilot projects + mvdXML specifications to support data checking
WP8		Input for standardization activities • mvdXML specifications • proposals for improvement of mvdXML • use cases for ifcOWL

The following deliverable D5.2 on “Semantic Web based PMO (Product Modelling Ontology)” will include the results of the work done according to these recommendations.

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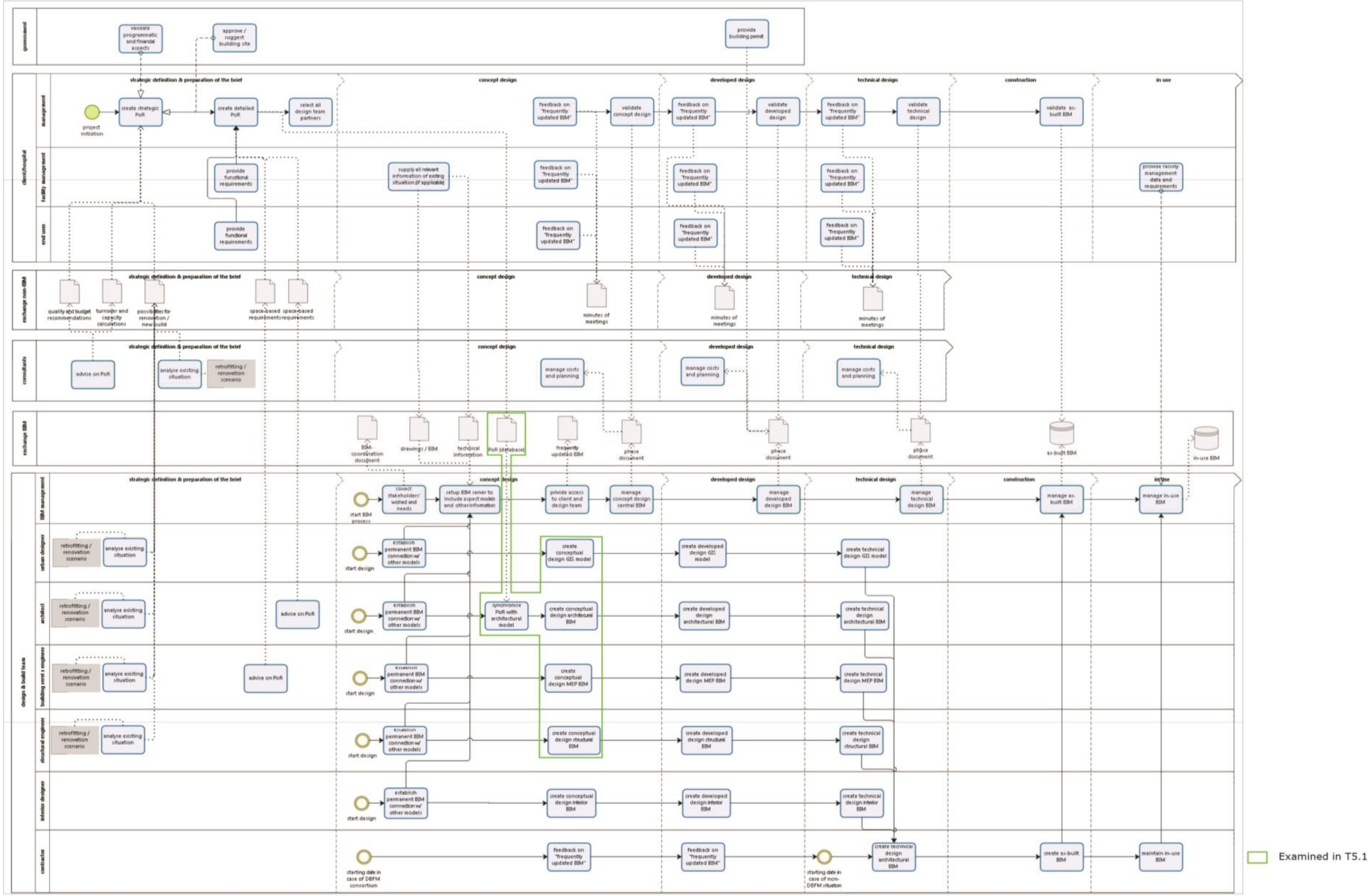
Links

LINKED DATA	http://www.w3.org/standards/semanticweb/data
LOD CONCEPT	http://www.w3.org/DesignIssues/LinkedData.html
SPARQL	http://www.w3.org/TR/sparql11-overview/
TBC	http://www.topquadrant.com/technology/topbraid-platform-overview/
PROTEGE	http://protege.stanford.edu/
LDP	http://www.w3.org/TR/ldp/
MARMOTTA	http://marmotta.apache.org/
BERLO_2012	http://www.zeep-architecten.nl/files/publicaties/106/ecppm2012-collaborative-engineering-with-ifc-new-insights-and-technology.doc_.pdf

APPENDIX 1 Design Process Map

The figure at next page shows an overview process map that reflects current work on defining the data flow in Streamer use cases.


government
validate programmatic and financial aspects
approve / suggest building site
provide building permit
client/hospital
management
facility management
end user
strategic definition & preparation of the brief
concept design
developed design
technical design
construction
in use
project initiation
create strategic PoR
create detailed PoR
select all design team partners
feedback on "frequently updated BIM"
validate concept design
validate developed design
validate technical design
validate as-built BIM
provide functional requirements
supply all relevant information of existing situation (if applicable)
provide facility management data and requirements
exchange non-BIM
quality and budget recommendations
turnover and capacity calculations
possibilities for renovation / new build
space-based requirements
minutes of meetings
consultants
advise on PoR
analyse existing situation
retrofitting / renovation scenario
manage costs and planning
exchange BIM
BIM-coordination document
drawings / BIM
technical information
PoR (database)
frequently updated BIM
phase document
as-built BIM
in-use BIM
design & build team
BIM management
urban designer
architect
building servi s engineer
structural engineer
interior designer
contractor
start BIM process
collect stakeholders' wished and needs
setup BIM server to include aspect models and otherinformation
provide access to client and design team
manage concept design central BIM
manage developed design BIM
manage technical design BIM
manage as-built BIM
manage in-use BIM
start design
establish permanent BIM connection w/ other models
synchronise PoR with architectural model
create conceptual design GIS model
create conceptual design architectural BIM
create conceptual design MEP BIM
create conceptual design structural BIM
create conceptual design interior BIM
create developed design GIS model
create developed design architectural BIM
create developed design MEP BIM
create developed design structural BIM
create developed design interior BIM
create technical design GIS model
create technical design architectural BIM
create technical design MEP BIM
create technical design structural BIM
create technical design interior BIM
starting date in case of DBFM consortium
starting date in case of non-DBFM situation
create as-built BIM
maintain in-use BIM
🟩 Examined in T5.1

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