SWIMING: H2020 - 637162

Semantic Web for Information Modelling in Energy Efficient Buildings

Deliverable number	**D1.2**
Deliverable title	**Business Use Cases for the use of BIM-LOD in BLCEM – Phase II**
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Grant Agreement number	637162
Project ref. no	H2020 - 637162
Project acronym	SWIMing
Project full name	Semantic Web for Information Modelling in Energy Efficient Buildings
Starting date (dur.)	01/02/2015 (24 months)
Ending date	31/01/2017
Project website	www.swiming-project.eu

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Document Identifier	D1.2

Class Deliverable	SWIMing EU-EEB-2015-637162
Version	v1
Document due date	31/07/2015
Submitted	31/07/2015
Responsible	Hendro Wicaksono (KIT)
Reply to	Hendro.wicaksono@kit.edu
Document status	Draft
Nature	R(Report)
Dissemination level	PU(Public)
WP/Task responsible(s)	WP1
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Distribution List	Consortium Partners
Reviewers	Kris McGlinn
Document Location	swiming-project.eu/?page_id

Executive Summary

This deliverable presents the final results of the effort in the SWIMing project related to WP1 on the identification of business requirements and use cases in Building Life-cycle Energy Management (BLCEM) processes, in particular, it is related to the identification and capturing of conceptual data models to support generation of building related Linked Data. The deliverable presents the results arising from work conducted through the W3C LBD Community Group and clustering workshops to identify and develop seed use cases. The deliverable summarizes the insights gained from this process as well as drawing some general conclusions, leading to a number of recommendations for BLCEM Linked Data in business and research projects.

Document Information

IST Project Number	H2020 - 637162	**Acronym**	SWIMing
Full Title	Business use cases for the use of BIM-LOD in BLCEM		
Project URL	www.swiming-project.eu		
Document URL	swiming-project.eu/?page_id=		
EU Project Officer	Jose Riesgo		

Deliverable	**Number**	D1.2	**Title**	Business use cases for the use of BIM-LOD in BLCEM – Phase II
Workpackage	**Number**	WP1	**Title**	Business use cases

Date of Delivery	**Contractual**	31th July 2016	**Actual**	31th July 2016
Status	version 1		final □	
Nature	prototype □ report ■ dissemination □			
Dissemination level	public ■ consortium □			

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Abstract (for dissemination)	
Keywords	SWIMing, use cases, data domain

Version	Modification(s)	Date	Author(s)
1	First draft	01/07/2016	Hendro Wicaksono, Kris McGlinn
2	Version for	22/07/2016	Ioanna Petri, Nikolaos Kaklanis,

	review		Dimitrios Tzovaras
3	Final version	30/07/2016	Hendro Wicaksono, Kris McGlinn, Ioanna Petri, Nikolaos Kaklanis, Dimitrios Tzovaras, Matthias Weise.

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List of Abbreviations

AHU	Air Handling Units
AI	Artificial Intelligence
ANFIS	Adaptive Fuzzy Neural Network
ANN	Artificial Neural Network
BAS	Building Automation System
BCS	Building Control System
BIM	Building Information Modelling
BIM-LD	Building Information Modelling – Linked Data

BIM-LOD	Building Information Modelling – Linked Open Data
BLC	Building Life Cycle
BLCEM	Building Life Cycle Energy Management
BMS	Building Management System
CF	Cohesion Fund
CHP	Combined Heat and Power
CSV	Comma Separated Values
DEEBDIP	Dynamic Energy Efficient oriented Building Design and Information Platform
E2B (OR EEB)	Energy Efficient Buildings
EC	European Comission
EEB	Energy Efficient Building
EEEF	European Energy Efficiency Fund
ELENA	European Local Energy Assistance
ERDF	European Energy Development Fund
ESF	European Social Fund
FCU	Fan coil Units
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HPU	Heat Pump Unit
HVAC	Heating Ventilation and Air Conditioning
HVACL	Heating, Ventilation, Air Conditioning and Lighting
ICT	Information and Communication Technology
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
LBD	Linked Building Data
LD	Linked Data
LOD	Linked Open Data
MCP	Model Based Predictive control
PF4EE	Private Finance for Energy Efficiency
PI	Proportional-Integral
PID	Proportional-Integral Derivative
PV	Photovoltaic
RDF	Resource Description Framework
RFID	Radio-Frequency Identification
RTU	Rooftop Units
SEFF	Sustainable Energy Financing Facilities
UWB	Ultra-Wideband
VAV	Variable Air Volume Boxes
W3C	World Wide Web Consortium
WSN	Wireless Sensor Network

Introduction and Methodology

This deliverable presents the final results of the effort in the SWIMing project related to WP1 on the identification of business requirements and use cases in Building Life-cycle Energy Management (BLCEM), in particular related to the identification and capturing of conceptual data models to support generation of building related Linked Data. The deliverable presents the results arising from work conducted through the W3C LBD Community Group and clustering workshops to identify and develop seed use cases. The deliverable summarizes the insights gained from this process as well as drawing some general conclusions, leading to a number of recommendations for the production of guidelines and best practices (WP2).

The work presented in the context of this deliverable has been advanced through the use of the methodology developed during the course of the project and which has been presented in D2.2 [1]. Here we briefly summarize the methodology again. It should be noted that this deliverable will only explore Task 1-4 of Figure 1 (below). Task 5-8 will be presented in D2.3 'Guidelines and best practices for BCLEM process and data management - Phase II' which will be available in M23.

Methodology for Use Case Capture

This section begins by presenting an adaptation of the IDM methodology to meet the specific needs of the BLCEM domain when developing use cases and identifying data requirements for the purpose of publishing BLCEM data. This methodology has been presented previously in D2.2[1]. The methodology is based upon both the IDM/MVD standard and also guidelines set down in a project which addressed linked data for managing data in smart cities, called the Ready4SmartCities project [2]. Figure 2 gives a high level overview of the Business Process Model Notation (BPMN) [3] for this methodology. Here we describe, again, the different steps.

Task 1-3 'Define BLC Stage', Define Actors and Roles' and 'Define Data Domains'

The purpose of Task 1 is to enable the quick identification of where in the BLC data is both generated and processed. The BLC stages have been defined within the context of the Linked Building Data community and consist of; Design, Construction, Commissioning, Operation, Retrofitting/ Refurbishment/ Reconfiguration, Demolition/Recycling. More fine grained definitions of processes may also be defined during this task which can then be aligned with a specific data exchange (see Task 4). It is possible to apply different modelling techniques to capture processes, for example processes may be defined more formally using BPMN (as is done in the IDM methodology), but this is not a mandatory requirement. In Task 2 the different actors involved in the different processes required to complete the use case are identified. The purpose of this process is to enable the quick identification of responsible stakeholders for generating and processing data exchanges.

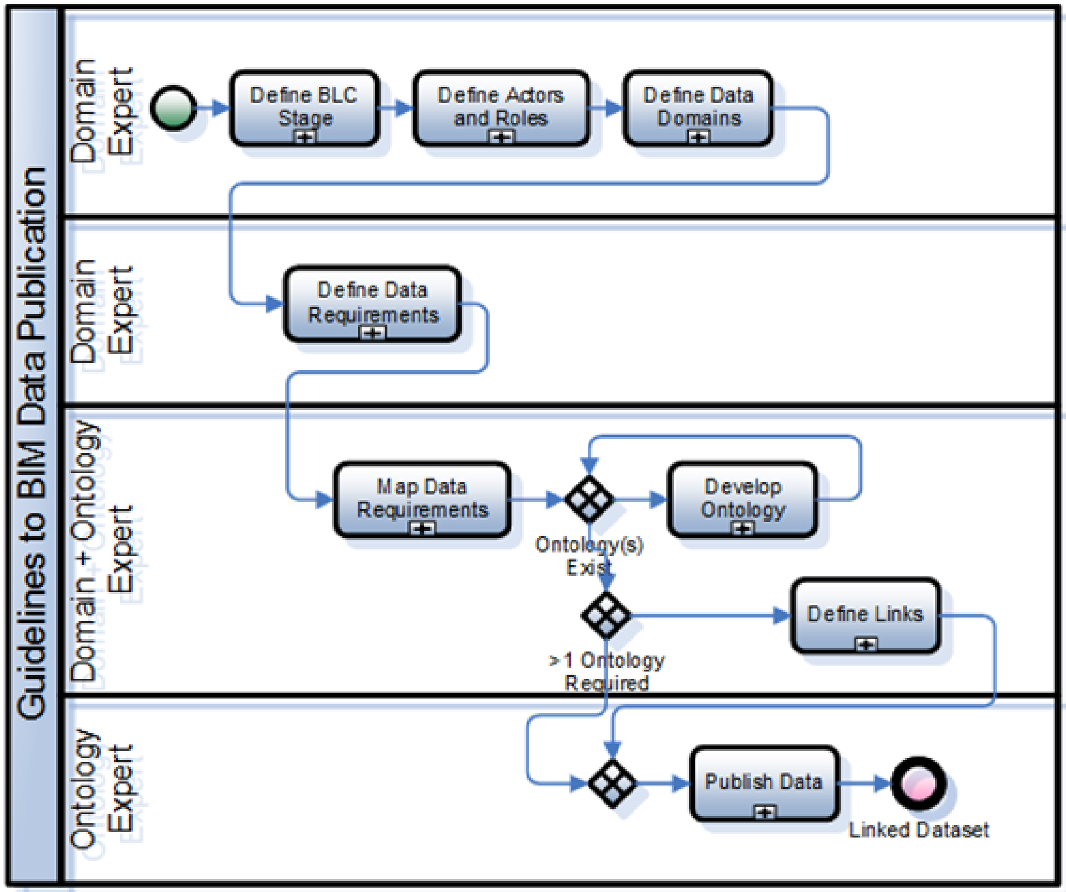

Figure 1 Methodology for generating and publishing BIM Data

For each process identified in the use case at least one actor must be defined who is responsible for generating that data. An actor may include non-human agents which process data and generate new data outputs.

In Task 3 the data domains that the use case requires are identified at a high level. The purpose of this process is to provide a quick reference to data structures best suited for a particular domain. These data domains are presented here [4] and include the following models; Product, Device, Control, Behavior, Communications (and Data Measures), Energy, Weather and Geolocation (geolocation has been extended to include District models). Once these three tasks are complete, the next step is to explore the data requirements in greater detail, assigning each data exchange requirement to its previously identified processes and actors.

Task 4-5 ‘Define Data Requirements’ and ‘Align Data Requirements’

In Task 4 the specific data requirements for each process in the use case are defined in greater detail. The purpose of this task is to understand the exact structure of the data required to meet the use case. Each data value that is required must be captured and described. This involves structuring the data as concepts and properties. These classes are then aligned with the processes and actors.

In Task 5 the conceptual model is aligned with existing ontologies and standards. The purpose of this task is to provide a quick reference point for the identification of alignments within existing domain models, thus supporting those who wish to enable similar use cases. The alignment process is based upon expert knowledge of the existing domain models and therefore may need to undergo several review steps to ensure that the data alignments are correct (see Task 8).

Task 6 - 8 'Develop Ontology', 'Define Links', 'Publish Data'

Task 6 is concerned with the development of models for meeting the data requirements of use cases which are not currently supported by any existing ontology or standard. The development of these ontologies should be conducted using existing methodologies and tools, for example, the Protégé tool [5], or the BIM*Q tool [6] (see next section) to provide lightweight ontologies. Where these new data structures are extensions of existing schema, they may also be used as a precursor to extending the schema for certification purposes.

Task 7 is concerned with the definition of links between ontologies and data models, where multiple are required to meet a use case. At this stage, the mappings and alignments identified in task 5 must be formalized, e.g. with equivalence statements (owl:equivalentClass/Property) as well as other types of linked properties. Finally, in Task 8 the publication of data so as to make it accessible both within the scope of a particular use case, but also to make it available to external use cases is addressed. It is envisaged that prior to the completion of this task all concerns related to licensing, security and privacy have been addressed. This deliverable will not address these last four tasks, instead focusing on the use of the BIM*Q tool for steps 1-4.

Tool Support for Use Case Modelling

To support the application of the outlined methodology, a web-based tool has been developed called the BIM*Q tool (previously known as ReqCap). This has been developed by AEC3 (AEC3 2016) and is the result of many years of experiences in collecting and structuring end user requirements. It replaces a former spreadsheet-based solution used within the IDM methodology, an approach which was originally chosen due to a low learning curve for new projects. However, experiences have shown that collected requirements quickly become complex and are then difficult to maintain and evaluate in spreadsheets. They are also difficult to re-use as there is no central repository of IDM documents to search for existing descriptions and data exchanges. Also, changes to one data exchange do not propagate to those derived from it without additional effort.

Besides these data management issues, there is also need to use collected requirements for sophisticated reporting and, based on the mvdXML format developed by buildingSmart, to export a specification which is usable for basic model checking. Accordingly, there are a couple of reasons to use the BIM*Q solution for collecting requirements. In the context of EeB projects, the application of the methodology described here along with tools like BIM*Q not only support the collection of requirements for a single EeB project, but also to share and reuse definitions with other projects, thus improving the impact of those projects by promoting their outcomes and enabling new projects to examine existing use cases, so as to reduce the time to align their data requirements with existing standards, for example, IFC.

The motivation of using a tool like BIM*Q is therefore not only to share requirements and all related definitions between project partners, but also to share it with other projects. The BIM*Q consists of a front end web-based interface which supports the modelling of data requirements and specifications that are relevant to implement a data exchange scenario. The initial setup consists of identifying the involved stakeholders (who is responsible to deliver that information), relevant stages and processes (when and why is something needed) (Task 1–3 Figure 1). Next, it enables the capture of relevant data exchanges in a structured way (Task 4). The tool has features to name and describe a use case, label and describe processes, label and describe stakeholders and capture at a conceptual level the different data requirements which can then also be associated with the processes and stakeholders. The conceptual data model may also be further annotated with suggestions for alignments with existing standards (Task 5), a step presented previously in D2.2 [1] and which will be presented in more detail in D2.3.

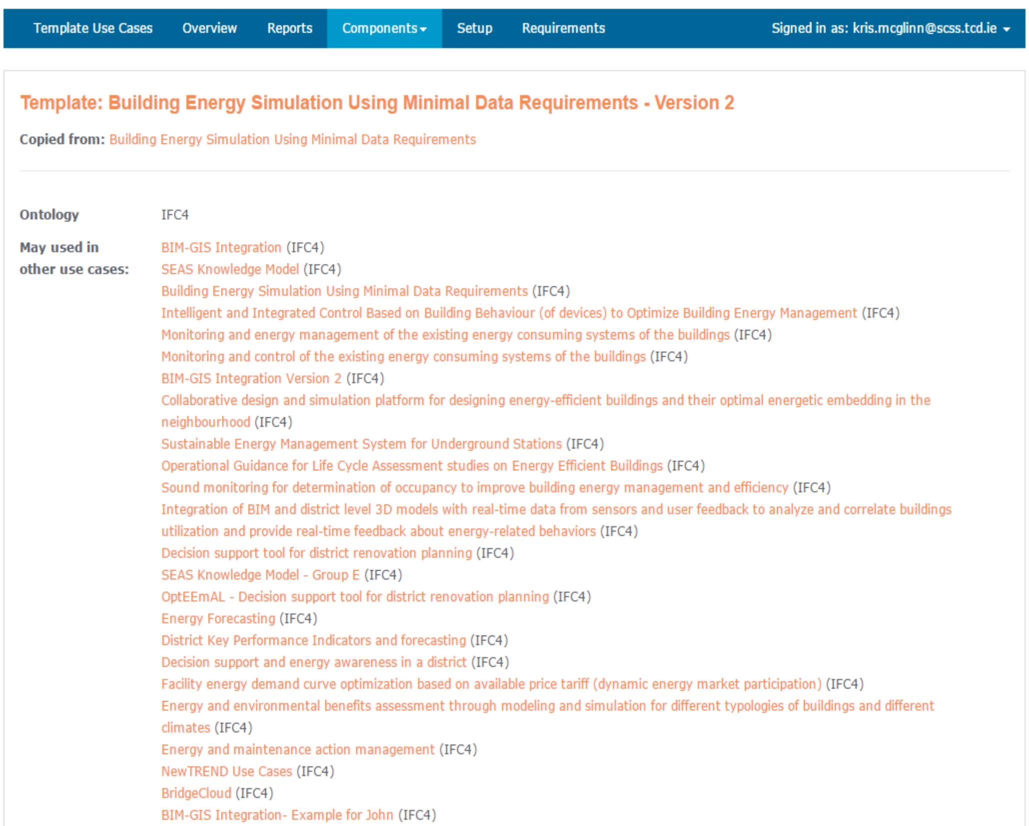

Figure 2 Use cases within BIM*Q which have indicated potential or actual alignments with IFC4 for data exchange

To give an illustrative example of how BIM*Q can be used for identification of standards related to use cases, Figure 2 presents a use case which has been selected for the purposes of discovering other use cases which share the same alignments to an existing data schema. The use case in this figure is presented below as UC-SIM 'Building Energy Simulation Using Minimal Data Requirements'. For this use case, a user working with BIM*Q can select an existing schema, e.g the IFC4 data schema. They then get a list of use cases which are also using this data schema. Further details about which parts of IFC4 are being used can be explored by clicking on the appropriate use case. While this deliverable does not explore the use of standards like IFC to meet the data requirements of use cases, it is useful to be aware of how the tool can be employed, and therefore, Figure 2 is presented to provide some context to the work conducted in this deliverable.

Execution of Methodology

Though the medium of the LBD Community, SWIMing has worked to capture the set of requirements and use cases to guide the development of best practice and guidelines for BIM data. **Requirements and use cases were gathered through the following channels**:

- An **online and printed survey** (32 responders) to gather initial input on requirements and use cases for BIM linked data, targeting the linked data, BIM and building energy research and user communities.
- Engagement with the European **research and industrial linked BIM data user community** at the BuildingSMART conference in Watford, London in England 23rd – 24th March 2015, primarily through a co-located, one day LBD use case gathering workshop on the 24th March 2015 (35 participants). This workshop also attracted several practitioners in BIM who had not yet engaged with linked data. The workshop included an interactive requirements and use case gathering session, which fed into the development of the data domains captured in D1.1. SWIMing engaged again with the community, presenting a description of the methodology developed in D2.2 in a workshop held at the BuildingSMART conference on the 14th April 2016 held in Rotterdam, Netherlands.
- Engagement with the **LDAC community**, which has developed around a workshop series and standardization activities organized by Jakob Beetz and Pieter Pauwels. This community gathers industry and public sector practitioners and researchers with a shared interest in interoperability of BIM content on the WWW. This community has exhibited a growing interest in BIM on the web and its relationship to BIM content and the use also of BLCEM technology on the Web. Engagement was conducted via the latest in the series of Linked Building Data workshops, organized by the LDAC and LBD community and held in Eindhoven 17th – 19th July 2015 and again in Madrid, Spain on the 22nd and 23rd of June. The former workshop is reported in deliverable D3.8 and involved an interactive requirements and use case gathering session. The latter workshop included an open discussion session around requirements for business use cases, and will be included in Report D3.11.

- Engagement with the VoCamp community at three events. The Vocamp workshops have been ongoing for several years and look at the development of vocabularies to support BLCEM. SWIMing has since 2015, taken over the task of organizing these events. The first VoCamp, an R4SC organized VoCamp in Genoa, Italy, was on supporting open linked data and interoperability for efficient energy systems in smart cities. It had 16 participants. The event looked closely at alignments between IFC and SAREF ontologies, as well as some cursory exploration of CityGML. SWIMing engaged with the participants defining alignments between ifcOWL and SAREF. The second VoCamp in Paris, France and organized by the SEAS project, had 50 participants over three days. A diverse set of topics were discussed and SWIMing had the opportunity to have multiple (3 one and a half hour session) with members of the SEAS project using the BIM*Q tool to capture use cases. The third in Dublin, Ireland organized exclusively by SWIMing. In this event use cases from 19 EU funded EeB projects were presented, and two interactive sessions were held which explored use case data requirements and alignments to standards.
- Engagement with the Sustainable Buildings community through the SWIMing workshop held at the University Campus of Savona, Italy and aligned with Sustainable Places. The workshop focused on clustering experts for presentations and discussion on research questions related with an open BIM approach for building lifecycle (BLC) energy management processes in buildings and more in general on standards and interoperability. It is co-organized by the EC funded projects EEBERS (ICT for EeB clusters) and SWIMing (Semantic Web for Information Management in Energy Efficient Buildings).

The detailed requirements and use case results from the first two activities listed above, together with further requirements and use cases gathered from public output of other groups and projects, were recorded in the preliminary deliverable D1.1. Over 50 high level use cases have been captured for 38 EeB projects. Results of ongoing requirements and use case gathering and analysis are posted as they emerge on the LBD wiki to inform and attract feedback from the community and also on the BIM*Q server.

Classification Framework

To help present some of the requirements and use cases gathered a broad categorization scheme was adopted to help differentiate major concepts of contributors and their overlaps. These are structured as follows:

- **Optimized Building Design for Energy Efficient Operation:** This covers use cases which fall under the design stage of the building and which are intended to result in energy savings during the operational phase of the building. This requires simulation of the buildings performance which may take into consideration thermal load, energy consumption and tariffs, ventilation and indoor thermal quality prediction, influences of (and on) occupants and weather data. These use cases make use of product, device, behavior, control, communications, energy, weather, geolocation and district domains.

- **Building Re-Design for Energy Efficient Operation:** This covers use cases which fall under the retrofitting, refurbishment and reconfiguration of building and which are intended to result in energy savings during the operational phase of the building. Here decision support tools are employed to analyze building materials and devices to provide feedback regarding new facades, devices, etc. to reduce energy consumption. These use cases can also take into account the behavior of occupants. They make use of product, device, district, behavior, control, communications, energy, weather, geolocation and district domains.
- **Optimized Building Use for Energy Efficient Operation:** This covers the largest number of use cases identified, which take place during the operational phase of the building. These use cases are mainly concerned with intelligent control of buildings through analysis of device data, occupancy data and through the use of predictive simulations. It is also concerned with tools which support visual analysis and feedback to stakeholders to inform about energy consumption for decision support and also knowledge of energy usage and energy tariffs to empower customers through modulation of device use. These types of use cases take into account the full spectrum of identified data domains.

These areas provide a structure for **categorizing use cases and requirements** and thereby targeting the portions of the community to engage with when advancing the best practice and guidelines activities in SWIMing. Next, the application of the SWIMing methodology is presented. This has been conducted using a tool called BIM*Q.

*Application of Methodology using BIM*Q Tool*

In the next section, a set of exploratory use cases taken from the LBD Seed Use Case wiki and which have been further explored using BIM*Q, are presented demonstrating the application of the first four steps of the methodology. Each use case is structured as followed: first, the use case title and a code for the use case are given, e.g. 'UC-NAME'. Next, the description of the use case taken from the LBD wiki [7] is presented, which also correspond to those initially provided in D1.1 [8]. Next, the processes in the use case are identified, followed by the stakeholders. Finally, a list of concepts and concept properties are provided along with a simplified UML diagram to give an overview of the relations which exist between the different concepts and domains to help readers when they wish to explore these.

The information which is available in the BIM*Q tool for each use case description should not be considered to be a complete description of all the possible data requirements; rather, the descriptions are part of an iterative process of defining and refining data requirements. After the use cases are presented, analysis is conducted which explores the relationships between the use cases. These will form the basis for developing alignments with existing standards and ontologies. This process has already begun and is presented in D2.2 [1] nd will be further explored in D2.3 (M23).

Application of SWIMing Methodology Across EeB Project Use Cases

This section presents a snapshot of the use cases which have been modelled in the BIM*Q tool. They are presented in a manner in which to illustrate the methodology defined in D2.2 and how this is being applied to support harmonization of data requirements across use cases. In all, seven exploratory use cases are presented, categorized by the three classifications presented previously; Design, Re-design and Operation. Six use cases are coded with reference to the project which has developed the use case, for example UC-EEEMBEDDED was developed in the EeEmbedded project. UC-SIM is an exploratory generic use case presented here to guide the reader when looking at the following use cases. Here is a list of the use cases by building life cycle stage:

Design

- UC-SIM 'Building Energy Simulation Using Minimal Data Requirements'
- UC-EEEMBEDDED 'Collaborative design and simulation platform for designing energy-efficient buildings and their optimal energetic embedding in the neighborhood

Re-design

- UC-STREAMER-1 'Energy efficient design of new and retrofitted buildings in healthcare districts'
- UC-OPTEEMAL Optimized Energy Efficient Design Platform for refurbishment at district level

Operation Stage

- UC-DAREED Decision Support Advisor for Innovative Business Model and User Engagement for Energy Efficient Districts
- UC-CASCADE Energy and maintenance action management
- UC-SEAM4US 'Sustainable Energy Management for Underground Stations'

Design Stage

UC-SIM 'Building Energy Simulation Using Minimal Data Requirements'

The first use case is an exploratory use cases developed for providing energy simulation based on minimal data requirements. Table 1 gives a description of this use case as taken from the LBD wiki [7].

Table 1 High Level Use Case Description – UC-SIM

Tag	Description
Title	Building Energy Simulation Using Minimal Data Requirements'

Description	This use case is concerned with enabling building energy simulation using a minimal set of data, for example, data on the floor area of the building, the ratio of window area, occupancy for zones, etc. Using this data it is possible to make predictions about kWh energy requirements for different zones in the building, which is then used to inform the responsible party about what building systems (e.g. HVAC) are required for installation and how they should be configured.
Objectives	1. Access and integrate minimal set of data to enable energy prediction 2. Run predictive energy simulation
Stakeholders	• Architect – Contributes data on building envelope, spaces • Building/Facility Owner – Contributes data on building behavior • Energy Manager/Auditor Operations Manager – conducts energy simulation
Data Domains	Products, Behavior
LD Benefits	Ease of access to required data
Challenges	Data representation, accessibility and reliability
BLC Stage Data Consumed	Design, Operation
BLC Stage Data Generated	Design, Operation
Available Datasets	<none>
Wiki Contributor	Kris McGlinn (TCD)

Table 2 defines the processes in more detail. These all take place during the design stage (Task 1 of the methodology). Next, slightly more detail regarding the Data domains (Task 3) is provided for a quick reference to other use cases which are interested in similar data domains. More information on the different top-level data domains and how they have been identified (i.e. product, behavior) can be found here [4].

Table 2 The different processes within UC-SIM.

Code	Name	Description	BLC Stage
P00	Check Net Floor Area	Determine the net floor size.	Design, Operation
P01	Building Material Specification	Determine the building materials.	Design, Operation
P02	Window to wall ratio calculation	Calculate window to wall ratio.	Design, Operation
P03	Energy Demand Calculation	Calculate energy demand.	Design, Operation

Table 3 Specific concepts and requirements for each data domain - UC-SIM

Domain	Specific requirements
District	• **Site:** Information about the site, including geometric properties, location, space information
Product	• **Building**: A description of the building which includes net floor area • **Facade**: A surface area of walls, windows, etc.
Behavior	• **Occupancy**: Heat load and comfort ranges for the building
Cross Domain	**Specific requirements**
Identification	• Objects require capabilities for uniquely identifying them
Location	• Objects have locations relative to a coordinate system. This can also include orientation
Space	• Objects are located in spaces. Spaces may also have occupancy schedules associated with them

Along with high-level data domains, it is also recommended to begin to identify the high-level concepts required within each domain (domain specific concepts) and cross-domain concepts, those which can be applied to multiple domains. Table 12 gives an overview of these concepts for UC-SIM.

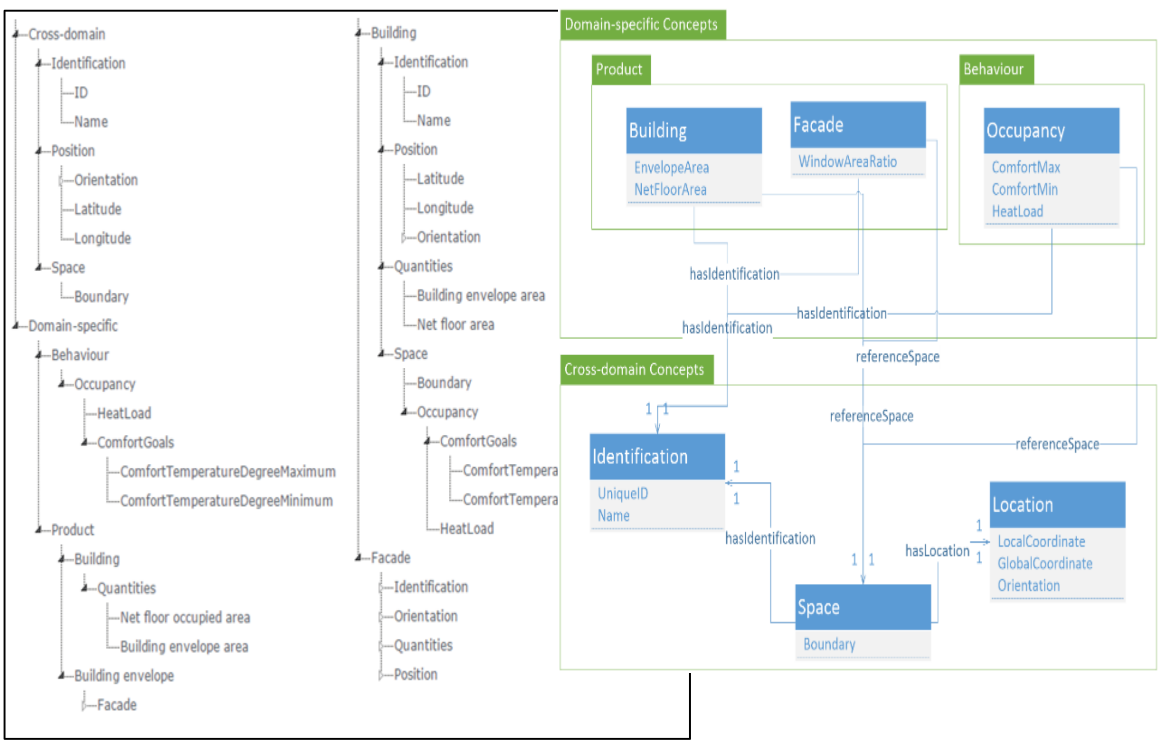

Figure 3 Left Image: UC-SIM Data Exchanges in the BIM*Q Tool (Left Classes by domains, Right Exchange Requirements). Right Image: Simplified UML class diagram to highlight relations between concepts - UC-SIM

Next, task 4 of the methodology looks at further dividing the data requirements into concepts and their properties. Figure 3 gives a screen shot of the data requirements as seen in the BIM*Q tool. On the left column of the left image the different concepts are organized as per the domains identified in Task 3. These are: (Product, Behavior) and generic cross-domain concepts which are related to multiple domains (Identification, Position and Space). On the right column of the left side figure we see the specific data exchanges which must be met to enable the use case. These include the properties for each concept, which are themselves be made of up of concepts. The tree has been unfolded for Building. Building requires some unique identification, its position (related to geolocation), some quantities to enable the predictive energy simulation, and a relation to occupancy through space, i.e. the building has a related space which gives the heat load and comfort range of the building.

Figure 3 (right) gives an overview of the different concepts as described in a Simplified UML Class diagram [9]. Concepts from BIM*Q are described here as classes (e.g. Building, Façade, Space) and properties (e.g. UniqueID.) and associations/relations (e.g. hasIdentification) are given. While more subclasses are indicated in the BIM*Q tool, here we include only the important classes, properties and relations to highlight the relationships between these for illustrative purposes. To adhere to RDF principles, relations are directed. The UML diagram helps to reveal how relations can be used to link concepts to each other, which indicates what concepts may be best suited for alignment purposes, and which then form the basis for LD linking between generated data sets.

Once the collection of concepts and their properties are defined, the next step is to make a choice about which model (or models) can best support the use case (Task 5). We do not cover this step in this deliverable, and this information will be presented in D2.3. In this deliverable, as explained previously, the focus is on identifying high level concepts and harmonization of these concepts across use cases which we present at the end of this section.

UC-EEEMBEDDED 'Collaborative design and simulation platform for designing energy-efficient buildings and their optimal energetic embedding in the neighborhood

This use case looks at the development of an open BIM-based model to support holistic collaborative design and simulation based upon a related holistic design methodology. Table 4 gives a description of this use case as taken from the LBD wiki [7].

Table 4 High Level Use Case – UC-EEEMBEDDED

Tag	Description
Title	Collaborative design and simulation platform for designing energy-efficient buildings and their optimal energetic embedding in the neighborhood
Description	The use case should result in the development of an energy

	system information model (ESIM) to support an integrated information management framework for designing energy-efficient buildings and their optimal energetic embedding in the neighborhood of surrounding buildings and energy systems. As such, it covers a wide range of both specific and cross data domains and can be seen as a template for guiding EeB projects when examine their own data requirements.
Objectives	1. Develop a design control and monitoring system based on hierarchical KPIs 2. use of knowledge based detailing templates to allow energy simulations in the early design phase 3. BIM-enabled interoperability grounded on a novel system ontology (Link Model providing the bridge between the multiple physical and mathematical models)
Stakeholders	Building/Facility Owner, Architect, Operations Manager, Energy Manager/Auditor, Facility Manager, Engineer HVAC, Engineer Building Energy Management System, Engineer Automation, Engineer HVAC, Financial/Cost Manage
Data Domains	District, Products, Device, Control, Communication, Behavior, Energy
LD Benefits	Different data sources can be linked together to an Dynamic Energy Efficient oriented Building Design and Information Platform (DEEBDIP)
Challenges	Integrate three levels of design: (1) Neighborhood, (2) Building and (3) Room.
BLC Stage Data Consumed	Planning and Design, Operation and Retrofitting/Refurbishment/Reconfiguration
BLC Stage Data Generated	Planning and Design, Operation and Retrofitting/Refurbishment/Reconfiguration
External Sources	eeEmbedded website (http://eeembedded.eu/)
Available Datasets	<none>
Wiki Contributor	Matthias Weise (AEC3), Kris McGlinn (TCD)

Table 5 The different processes within UC-EEEMBEDDED.

Code	Name	Description	BLC Stage
P00	Develop Architectural Model	An architectural model is developed, e.g. by an architect	Design
P01	Develop HVAC Model	An HVAC model is developed, e.g. by an HVAC Engineer	Design
P02	Develop BACS Model	An BCS model is developed, e.g. by an automation engineer	Design
P03	Develop FM Model	A model of the buildings schedules is developed, e.g. by the Facility Manager	Design
P04	Generate Energy Simulation Model	A predictive energy simulation model is generated automatically	Design

Table 5 defines the processes (Task 1) (as extracted from the publicly available deliverable for EeEmbedded [10]). The use cse examines an incremental approach to the development of an energy simulation model. First, architectural models are expected to be design and developed. These are then enhanced with HVAC models which describe the different Heating, Ventilation and Air conditioning systems. Next the building automation and control systems are designed, and leading from these the expected behavior of the building during operation are described in the Facility Management (FM) model. From these models the ESIM model can be automatically generated.

The data domains of interest are directly related to each model developed at each process. These have a correlation between the data domains identified in SWIMing. P00 for Product, P01 Device, P02 Control, P03 Behavior and P04 Energy. Here we give a quick overview of the domain specific concepts and also the cross domain concepts in Table 12.

Table 6 Specific concepts and requirements for each data domain - UC-EEMBEDDED

Domain	Specific requirements
District	• **Site:** Information about the site, including geometric properties, location, space information
Product	• **Building**: Information about the building, including geometric properties, location, can include building envelope. • **Building Storey**: Information about the storey, including geometric properties, location, space information.

Device	• **Energy Storage System**: Various storages types are available on large scale district level and on building level, storing e.g. electricity, heat, natural gas, hydrogen or potential energy within pumped-storage power plants. • **Energy Distribution System**: A unified description and public access data repository which contains information about preferred areas for district heating / cooling should be supported • **Energy Transformation Facility**: description of connecting systems combined with operational limits and restrictions by law. • **Sensor**: describes a sensing device • **Actuator:** describes an actuator • **Controller**: describes a controller for controlling sensors and actuators.
Control	• **Control Function**: room automation function, BACs function, and management functions. • **Control Strategy**: optimization based on short term, long term and operational periods.
Communications and Data	• **Interface:** A description of the interface to a device**, e.g. communication protocols** • **Data Point:** A structured message indicating, for example, a measurement.
Behavior	• **Device Behavior Model**: Behavioral characteristics may be included by device vendors, suppliers, service providers, designers or customers. • **Occupancy**: A description of density and occurrence in spaces, as well as interactions with user equipment (computers, and other use devices), building product (shading, windows) and electrical systems (lighting, temperature, ventilation)
Energy	• **Energy Input**: The (nominal) medium energy input into devices • **Energy Output**: The (nominal) medium energy output of devices • **Energy Source**: A unified description of energy resources.

Cross Domain	Specific requirements
Identification	• A way to uniquely identify an instance of a concept. Also included here is 'Type', which is a property shared across domain specific models in UC-EEEMBEDDED.
Location	• Exact location given as coordinate with reference frame.
Space	• Capture of volumes, can be used as a container for products, devices, etc.
Representation	• A method for visually representing an object, e.g. a geometric representation.
Cost	• Sales price of devices and (nominal) operational costs
Maintenance	• This aspect provides data structures for the description of maintenance related task during the operational phase of the system.
Coefficient of Performance	• The (normative) Coefficient of Performance (COP) represents a major criteria especially within the design process.
Reliability	• Failure rate and mean time to failure.
Risk Management	• Sustainability, vulnerability and cost related risks.
Administration	• Information used for management purposes, e.g. rent of system, business cases which includes contracting models, etc.
Geometry	• If geometry is needed, for example for visual representation.

Once again step 4 begins by dividing the data requirements into concepts and their properties. Figure 4 gives a screen shot of the data requirements as seen in the BIM*Q tool. On the left the different concepts are organized as per the domains identified in Task 3. These are: (District, Product, Device, Control, Communications and Data, Behavior, and Energy) and generic-concepts which can be related to multiple domains (Identification, Location, Cost, Coefficient of Performance, Maintenance, Reliability, Risk Management, Administration and Space).

On the right side we see the specific data exchanges. These include each property which must be met to enable the use case. The tree has been unfolded for Energy Source. Building requires some unique identification, its position (related to geolocation), some quantities to enable the predictive energy simulation, and a relation to Occupancy through Space, i.e. the building has a related space which gives the heat load and comfort range of the building.

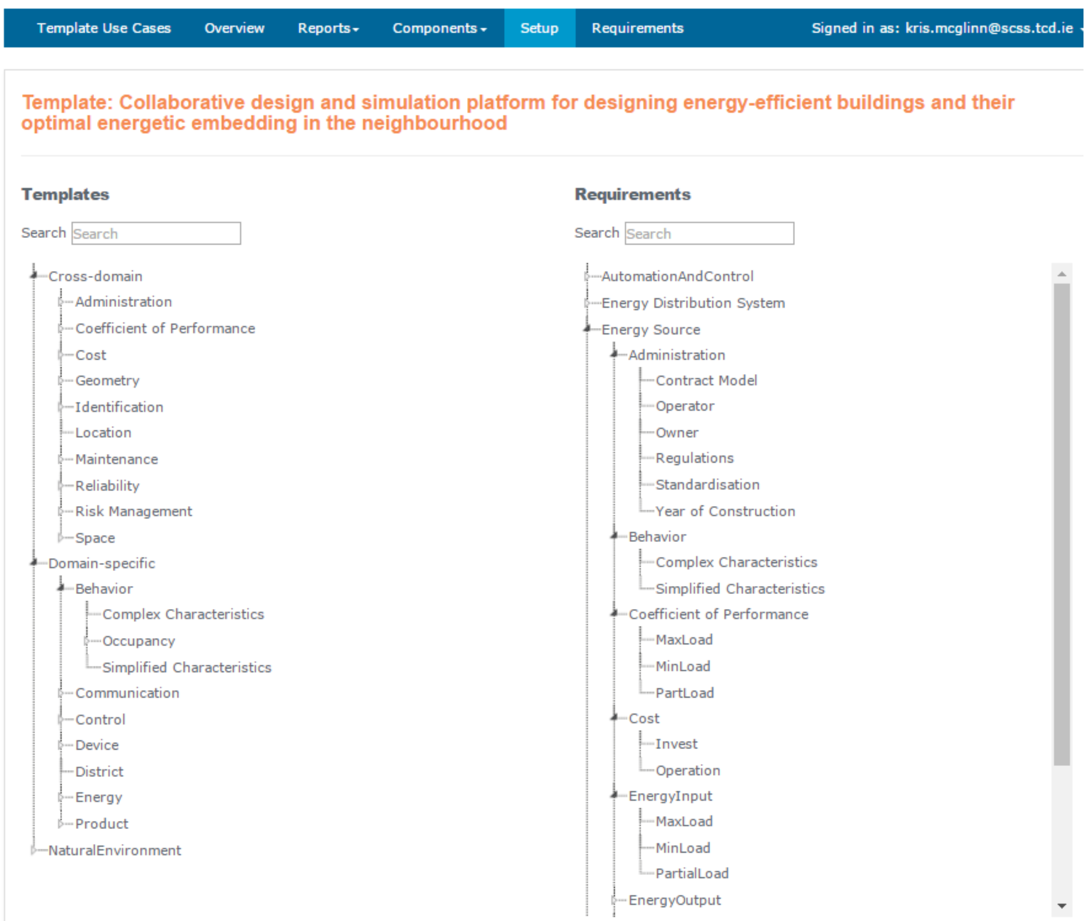

Figure 4 UC-EEEMBEDDED Data Exchanges in the BIM*Q Tool (Left Classes by domains, Right Exchange Requirements)

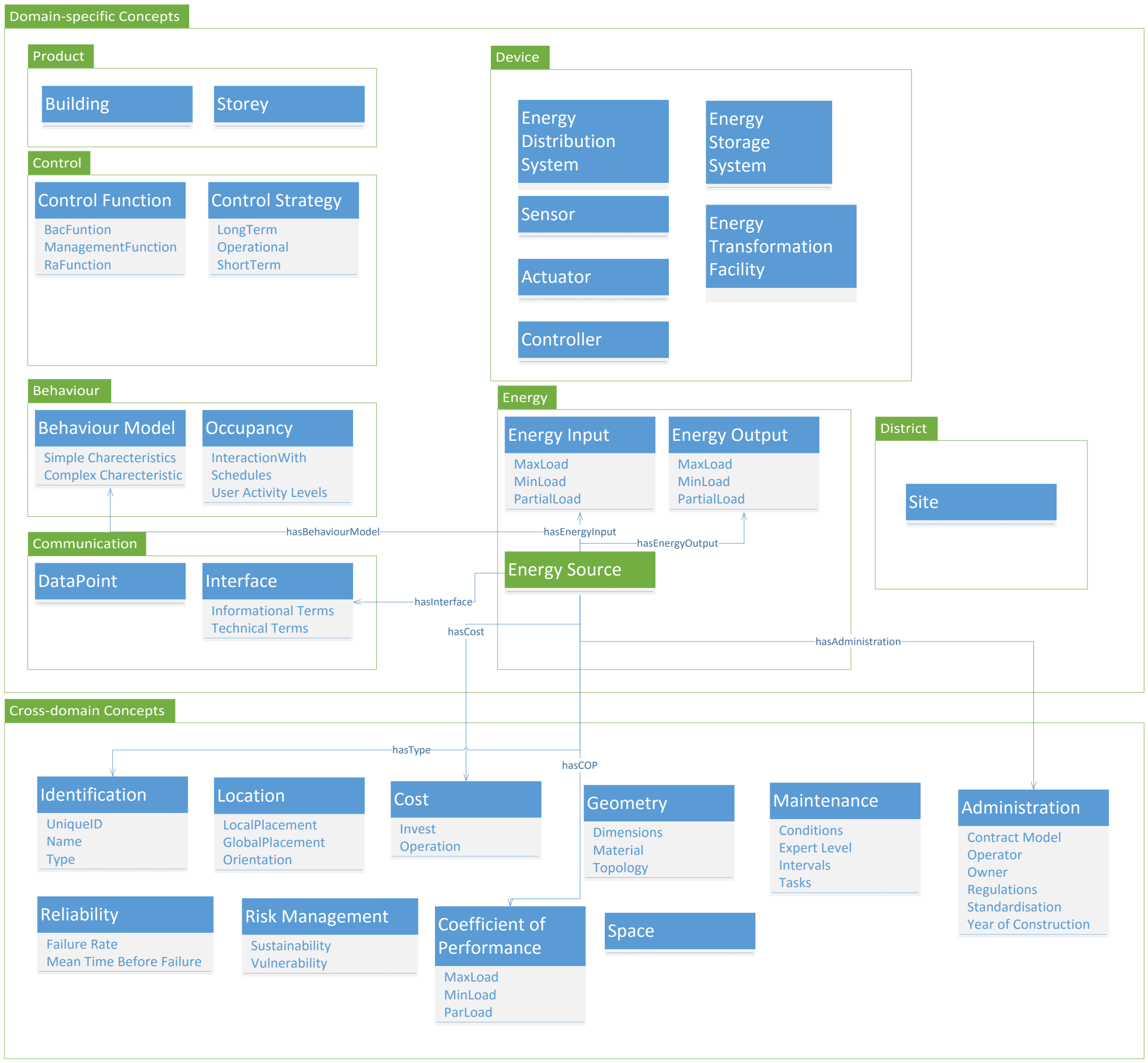

Figure 5 Simplified UML class diagram to highlight relations between concepts. Only Energy Source has relations visible. – UC-EEEMBEDDED

Figure 5 gives an overview of the different concepts as described in a simplified UML class diagram. In this figure, the only concept to have relations defined is 'Energy Source'. This is due to the number of relations making any single diagrammatic representation cluttered. Energy Source demonstrates the types of relations that are required between the different concepts and once again helps to reveal how relations can be used to link concepts to each other, which indicates what concepts may be best suited for alignment purposes, and which then form the basis for LD linking between generated data sets. Here we see an Energy Source requires Identification, a Coefficient of Performance, a Cost model, an interface model, a behavioral model, an administration model and energy input and output. For more information on these concepts and relations, it is advised you consult the appropriate deliverables on the EeEmbedded website.

Re-design Stage: Retrofitting, Refurbishment and Reconfiguration

UC-STREAMER-1 'Energy efficient design of new and retrofitted buildings in healthcare districts'

Table 7 gives a description of this use case as taken from the LBD wiki [7].

Table 7 High level use case description –UC-STREAMER

Tag	Description
Title	Energy efficient design of new and retrofitted buildings in healthcare districts
Description	This use case is focused on energy efficient design of hospitals taking into account the interrelationships to other buildings in a healthcare district. It covers two main use cases, new design and retrofitting of buildings. It is dealing with early design processes trying to develop a rough building layout based on client requirements and generic design rules for hospitals. The expected energy consumption is one of the key performance indicators for the evaluation of a design proposal generated with genetic algorithms. Other KPIs such as comfort or building life-cycle costs are also considered in the decision processes, which essentially is the aggregation of the most important figures of a design proposal.
Objectives	1. Knowledge-based modelling of integrated EeB technologies and measures, optimally integrating these EeB design solutions, and validating the whole lifecycle energy performance during the design stage 2. Provide the multidisciplinary design teams with advanced design tools by improving the open interoperability between Building Information Modelling (BIM) and Geographical Information System (GIS) in a Semantic Web (SW) environment, and by enabling model-based analysis of the energy performance. 3. Effectively manage information flow, knowledge integration, communication and decision-making in the participatory semantics-driven design process according to the principles of Integrated Project Delivery (IPD).
Stakeholders	Building/Facility Owner, Architect, Energy Manager/Auditor, Engineer HVAC
Data Domains	Product, Device, Actor and District, Geolocation and Weather
LD Benefits	Enable to link data from different data sources (in particular BIM and GIS)

Challenges	Capture design rules to assist the design team in transferring client requirements into energy efficient design. Expand building design to district level
BLC Stage Data Consumed	Design, Re-design
BLC Stage Data Generated	Design, Re-design
Available Datasets	<none>
Wiki Contributor	Matthias Weise (AEC3)

The workflow for design and re-design are similar and shown in Figure 6. The main difference between these two is the number of constraints. For example, in the case of re-design limitations for the new space layout due to the existing load bearing structure may be required. Accordingly, STREAMER covers the BLC stages design as well as re-design, which have similar data requirements. Another difference for the re-design use case is to support the capability to compare the expected building behavior with measured data from the existing building.

Table 8 shows the stage and process definition (Task 1 of the methodology). Stakeholders have been identified on a rather high level not going into too much detail. The identified stakeholders (Task 2) can be seen in Table 7. This is an intermediate list that may change or needs a project specific configuration. Data requirements on a high level are linked with the following domains as extracted from data provided into the BIM*Q tool (Task 3) and presented in Table 9. Once again, this is not fully representative of all the data domains required within this class, but only those which have currently been added as exchange requirements into BIM*Q.

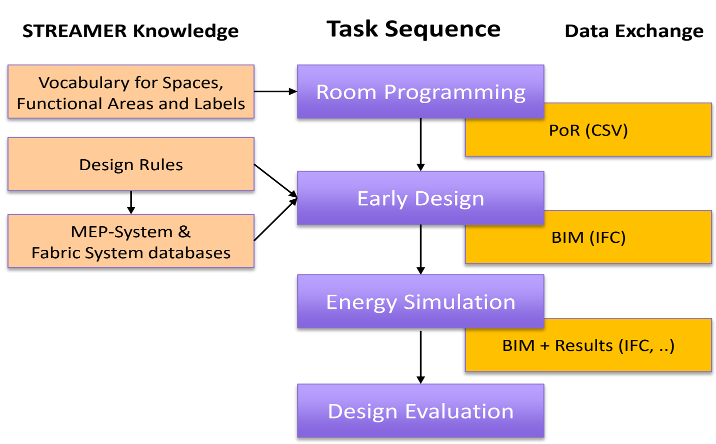

Figure 6 Main workflow in STREAMER (taken from D5.2)

Table 8 The different stages and processes within UC-STREAMER

Code	Name	Description	BLC Stage
S01	Early Design		
S01-P01	Early Design by Briefbuilder		Early Design
S01-P01a	Early Design by Design Configurator with room types		Early Design
S01-P01b	Early Design by Design Configurator without room types		Early Design
S01-P02	Output Design Configurator		Early Design
S01-P03	Output of Energy Analysis		Early Design

Table 9 Specific concepts and requirements for each data domain - UC-STREAMER

Domain	Specific requirements
District	• **Site:** Information about the site, including geometric properties, location, space containment
Product	• **Building**: Information about the building, address, location, space containment • **Building Storey**: Information about the storey, location, space containment . • **Room**: Detailed information about a room, including location, space information, representation, HVAC and lighting systems, comfort requirements, construction, safety, air quality, etc. • **Functional Area**: Represents the functional characteristics of a space, for example a room.
Device	• **HVAC**: Information about the heating, ventilation and air-conditioning system • **Lighting**: Information about lighting
Actor	• **Interface:** A description of the interface to a device**, e.g. communication protocols** • **Data Point:** A structured message indicating, for example, a measurement.
Cross Domain	**Specific requirements**
Identification	• A way to uniquely identify an instance of a concept. Also included here is 'Type', which is a property shared across domain specific models in UC-EEEMBEDDED.
Placement	• Exact location given as coordinate with reference frame and geolocation.
Space	• Capture of volumes, can be used as a container for products, devices, etc.
Representation	• A method for visually representing an object, e.g. a geometric representation.
Units and Height level	• Units used to describe aspects of the different concepts, e.g. the area, length, volume of a space and the elevation and height name of a space.

A concept that was developed in the STREAMER project is the label approach that is introduced with the first process, the Program of Requirements (PoR). The PoR process captures the (client) requirements of a design. In the early design stage not all information is available. The introduced label methodology means that requirements are translated into more generic information containers, the so called labels. These labels represent semantic information and are used by different tools. Accordingly, the meaning of the labels must be formalized and has to be static throughout the design process.

The most detailed concept presented in this use case is the concept of a ‘Room’ (see Figure 7.), which has several properties which are not explored here in detail. An example of one of these is the “comfort class” concept, which represents requirements for light, daylight, ventilation and design temperatures. This label is first used to describe the wishes from the client regarding those aspects. Secondly they are used as a way to produce a layout possibly by placing the rooms with daylight requirements next to the outer wall.

A next step is an early energy simulation where the simulation tool uses the design temperatures of the “comfort class” label as an input for calculating the heating and cooling requirements. For all those different purposes the label (value) needs to represent the same semantic information and must be used in the same way in each use case. Therefore the labels are fixed and static throughout STREAMER.

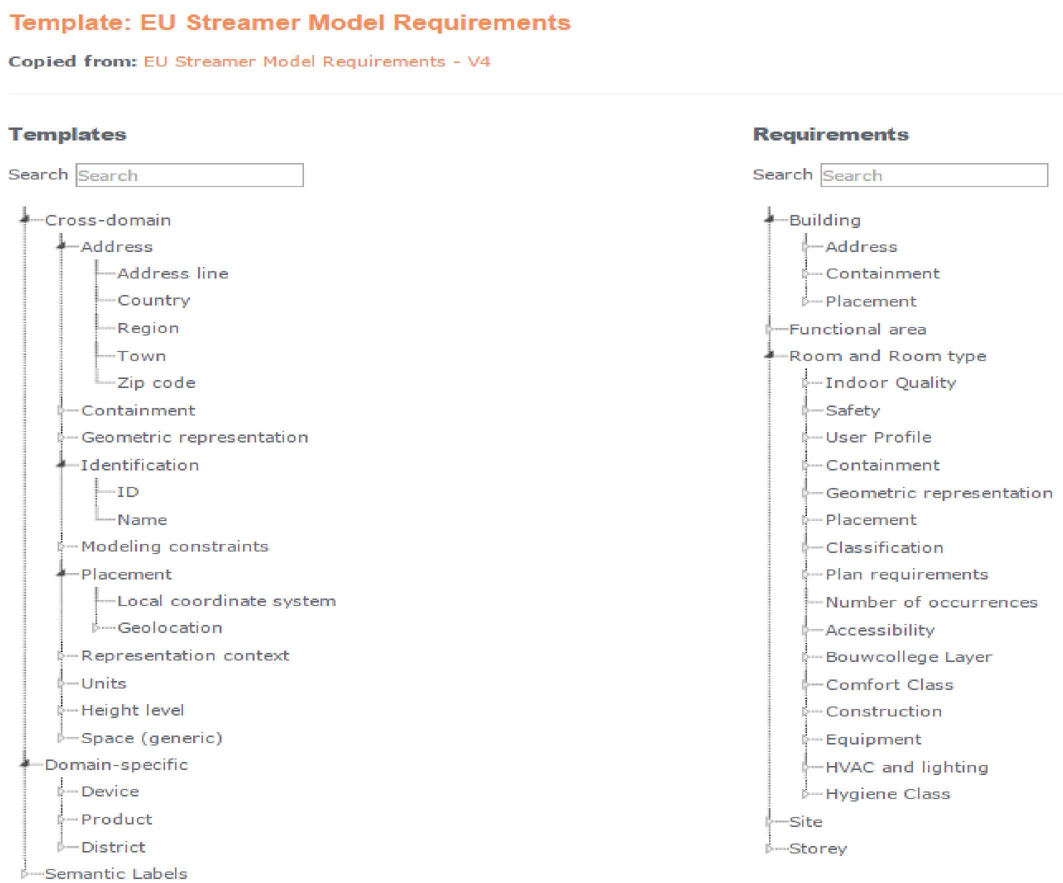

Figure 7 Screenshot from the BIM*Q tool capturing STREAMER requirements.

Figure 7 shows a screenshot from the BIM*Q tool. The semantic labels such Accessibility, Equipment or Hygiene Class are attached to space types (Room is a space type), which is the main object for carrying client requirements. Beside the labels itself, allowed values are defined that are linked with constraints for the design. They implicitly define for instance the type of required ventilation type (e.g. natural or controlled) or if a space must have a position next to an outer wall (if daylight is required). This knowledge is captured in separate design rules and are not represented in the BIM*Q tool.

As described above, the labels remain in the BIM, but for instance need to be linked with designed spaces[1] to be available for further energy calculation processes. The focus for task 4 (identification of concepts) was on client requirements. Accordingly, there some similar terms for main concepts like Space, Room (including Space Type and Room Type) and Functional area. In addition to this, there are typical high-level concepts such as building, building storey and site (see Figure 8).

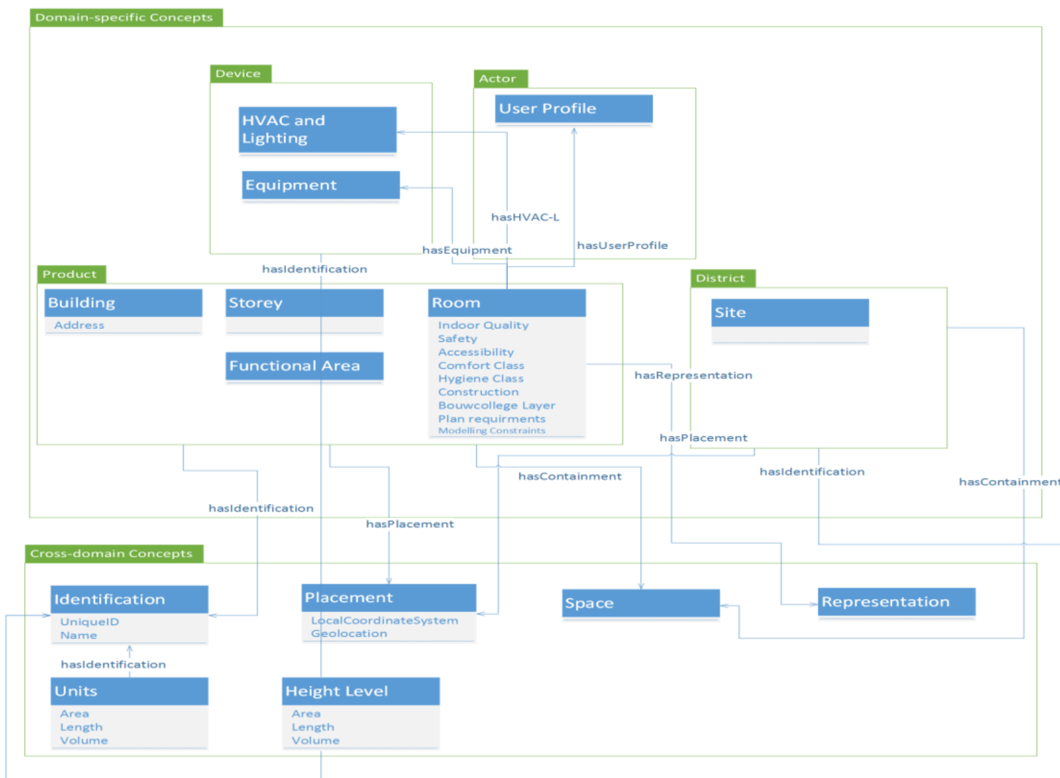

Figure 8 Simplified UML class diagram to highlight relations between concepts . The focus here is on the Room concept and related concepts. – UC-STREAMER

[1] The first step defines requirements for space types, include the number of required space types. The early design then creates real spaces for the requested space type.

UC-OPTEEMAL Optimized Energy Efficient Design Platform for refurbishment at district level

Table 10 gives a description of this use case as taken from the LBD wiki [7]. This use case is in the early stages of being defined through the application of the BIM*Q tool.

Table 10 High level use case description –UC-OPTEEMAL

Tag	Description
Title	Decision support tool for district renovation planning
Description	Developing decision support tools to assist district renovation planning, integrating the needs of different stakeholders: inhabitants, local authorities and business investors. These tools will give the opportunity to select stakeholders' highest priorities and report building renovation scenarios. The tools will specifically assess related costs & benefits, as well as environmental & social impacts at a district level.
Objectives	1. To integrate stakeholders' needs in a single software environment 2. To enable analysis of different scales and different time frames 3. To create a versatile tool with an open structure 4. To facilitate day to day work of future users
Stakeholders	Building/Facility Owner, Operations Manager, Financial/Cost Manager, Occupant, Urban planners, Housing corporations, Engineering companies
Data Domains	District, Product, Energy, Actor
LD Benefits	Structured common vocabularies for building aspects (size, materials, use and occupancy patterns, etc.) allowing data integration
Challenges	Integration of required data, interoperability.
BLC Stage Data Consumed	Retrofitting/Refurbishment/Reconfiguration
BLC Stage Data Generated	Planning and Design, Operation and Retrofitting/Refurbishment/Reconfiguration
External Sources	http://cordis.europa.eu/project/rcn/198378_en.html
Available Datasets	<none>
Wiki Contributor	Nick Kaklanis (CERTH), Kris McGlinn (TCD)

Table 11 defines the processes (Task 1).

Table 11 The different processes within UC-OPTEEMAL

Code	Name	Description	BLC Stage
01SUANP	Set-up a New Project		Design
02DDM	District Data Modelling		Design
04GS	Generate Scenarios		Design
05OS	Optimize Scenarios		Design
06SACS	Select and Complete Scenario		Design
07ESD	Export Scenario Data		Design
08SI	Show Information		Design
09SIMS	Simulate Scenarios		Design

The next step (step 3) of the methodology is “define data domain.” The data domains identified for the OptEEmAL use cases are described in more detail in Table 12.

Table 12 Specific concepts and requirements for each data domain - UC-OPTEEMAL

Domain	Specific requirements
District	• **Site**: Information about the site, including location • **District Performance**: Information about the performance of the district
Product	• **Building**: Information about the building, including geometric properties, location, can include building envelope. • **Building Storey**: Information about the storey, including geometric properties, location, space information.
Actor	• **User**: Information about ‘users’ of the buildings
Energy	• **SecondLevelBoundary**: Information about the materials on the surfaces of spaces.
Cross Domain	**Specific requirements**
Identification	• Properties for uniquely identifying objects (i.e name and category)
Location	• Basic description of the placement of spatially-located things/sensors/devices etc
Space	• Data regarding volumes of spaces, numbering (in case of rooms and whether a space is interior or exterior, whethere the space contains other spaces, or is contained by a space.
Representation	• A method for visually representing an object, e.g. a geometric representation.
Project	• Information relevant to the entire project, e.g. units of measurement
OwnerHistory	• Provenance data

Figure 9 gives an overview of the different concepts as described in a Simplified UML Class diagram. In this figure, not all relations are defined. Here we see that all concepts within the domain product require identification, placement and a containing spatial structure relation. For clarity, the relations are associated with the Product package domain. In the case of the Energy domain, we see that SecondLevelSpaceBoundary can be associated with another of these elements. It is envisaged that these types of associations may exist for other concepts also.

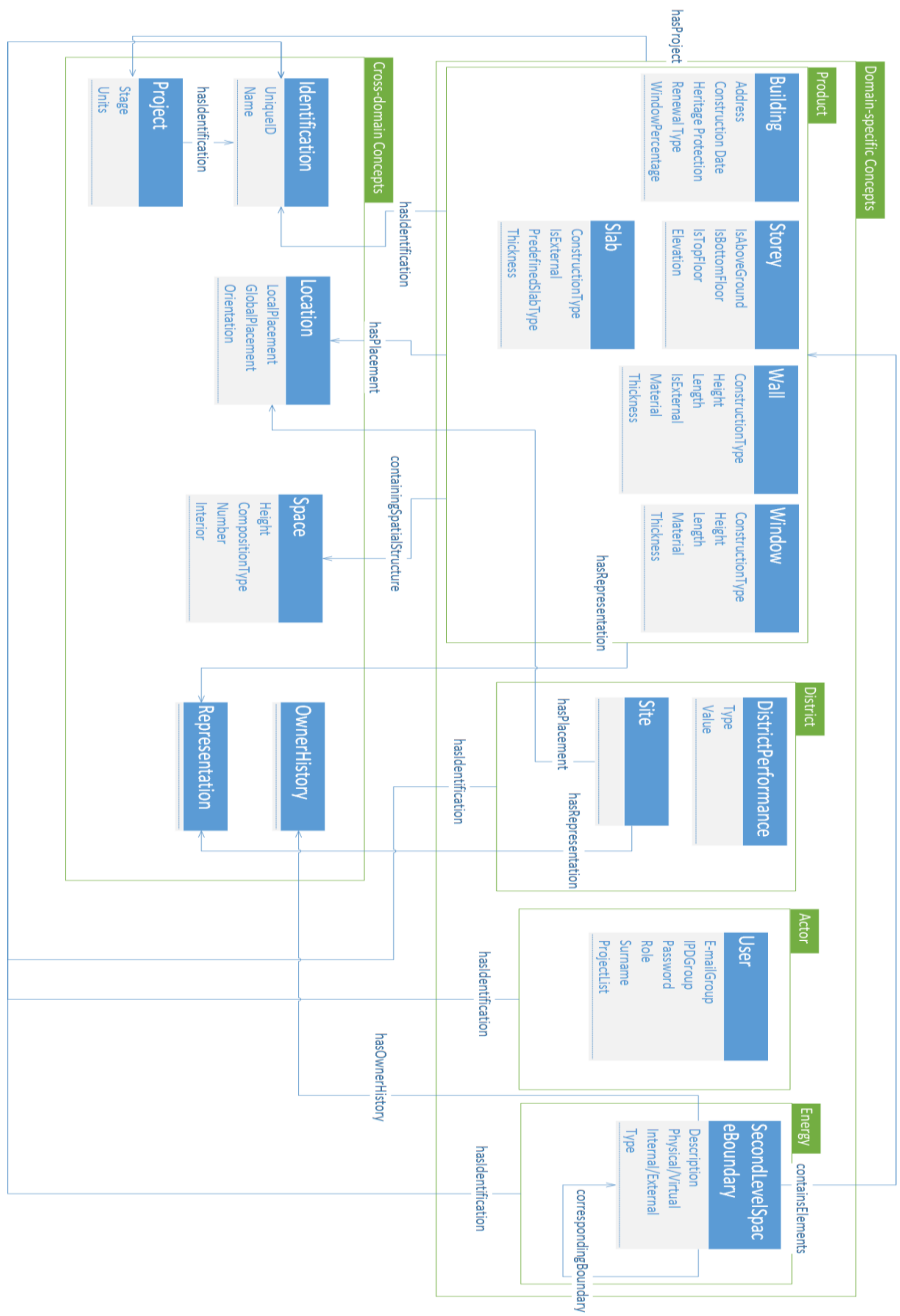

Figure 9 Simplified UML class diagram to highlight relations between concepts – UC-OPTEEMAL

Operation Stage

UC-DAREED Decision Support Advisor for Innovative Business Model and User Engagement for Energy Efficient Districts

This use case is from the DAREED project and is concerned with a platform for energy efficient district which enables active engagements of different stakeholders such as citizens and authorities.

Table 13 High level use case description – UC-DAREED

Tag	Description
Title	Decision Support Advisor for Innovative Business Mode and User Engagement for Energy Efficient Districts
Description	This use is concerned with a platform which is capable of receiving information from various sources, analyze the energy consumption taking place, and provide information and advice to both citizens as utilities and public institutions, involving all stakeholders in the process of improving energy efficiency. With this platform, the citizen becomes an active subject and decisiveness. He will meet his daily consumption curve -through mobile alerts, emails or other system- and the actions he can take to reduce it (DAREED 2016).
Objectives	1. Analyze and compare energy consumption pattern 2. Monitor and analyze district efficiency 3. Support definition of new tariffs and programs
Stakeholders	• Citizen, any end user who consumes energy in their activities, involved in UC-DAREED-1 and UC-DAREED-2 • Policy maker, authorities who are responsible for planning and improving energy consumption and generation in a district, involved in UC-DAREED-2 • Energy provider, companies who define pricing schemas based on customer behavior analysis, involved in UC-DAREED-3
Data Domains	Product, Device, Behavior, Building Data, Energy, Geolocation and Weather
LD Benefits	Data integration to address interoperability problem Data/resource locator Enables links between unrelated data
Challenges	Data representation, accessibility and reliability
Data Consumed	Design, Operation
Data Generated	Design, Operation

Available Datasets	<none>
Wiki Contributor	Hendro Wicaksono (KIT)

The use case can be broken down into three sub use cases:

1. Analyze and compare energy consumption pattern (UC-DAREED-1).
   This use case deals with providing information for energy consumer/citizen to be more capable of adapt their consumption patterns based on dynamic energy prices. Citizens will obtain valuable information that could help them to reduce their energy costs as they will be aware of how much does energy cost in each period of the day and how could they modify their energy demand.

2. Monitor and analyze district efficiency (UC-DAREED-2)
   This use case collects all the data which is created by on-site metering devices generating feedback of energy use in the grid. The gathered information will then be available for the different users, arranged in the most appropriate way for their use and serve in a homogeneously form. The use case also provides the user with a forecast of energy consumption and production on district level, during a user defined time interval. This forecast will be based of energy models implemented in DAREED Platform which will characterize the district to be simulated, real consumption and production data retrieved (when available) or theoretical consumption patterns, meteorological databases and predictions (when available). Additionally, the use cases is concerned with fast and transparent knowledge retrieval, where the user will be able to see what the current consumption and energy flow of the district are, to select different periods of time and to compare the total energy consumption.

3. Support definition of new tariffs and programs (UC-DAREED-3).
   This use case is concerned to support the definition of a new tariff for a target district (or district subpart), described as a set of energy units. The user must choose one or more tariff schemes, to be used as templates. The system then employs combinatorial optimization techniques to select one of the proposed schemes and to adjust its parameters so as to optimize the value of a user-specified performance metric. Examples of tariff schemes include Time-of-use based pricing, Peak-based pricing, Dynamic pricing. The corresponding parameters to be optimized are the pricing levels or pricing curves.

Table 14 describes the processes and BLC stages involved in each use case identified in DAREED project (step 1). As seen in the table, in DAREED project, data are generated or required by the processes within design and operation stages. In DAREED project, there are three stakeholders, who are involved in completing the use cases and in generating and consuming the data (step 2 of the methodology). A stakeholder can participate in more than a use case, for example a citizen that can analyze energy consumption pattern as well as analyze and monitor district performance. The stakeholders are listed in Table 7.

Table 14 Processes and BLC stages of use cases in DAREED

Use case	Code	Name	BLC Stage
UC-DAREED-1	UC-DAREED-1-001	Upload bills	Operation
	UC-DAREED-1-002	Compare bills	Operation
	UC-DAREED-1-003	Retrieve user notification	Operation
UC-DAREED-2	UC-DAREED-2-001	Retrieve projections of district consumption and generation	Design, Operation
	UC-DAREED-2-002	Calculate district key performance indicators	Operation
	UC-DAREED-2-003	Analyze district performance	Design, Operation
	UC-DAREED-2-004	Fast knowledge retrieval	Design, Operation
UC-DAREED-3	UC-DAREED-3-001	Obtain price suggestions for a district	Operation
	UC-DAREED-3-002	Obtain price suggestions for groups of buildings	Operation
	UC-DAREED-3-003	Define demand response programme	Operation

The next step (step 3) of the methodology is “define data domain.” The data domains identified for the DAREED use cases are described in more detail in Table 15. All of the use cases in DAREED require data from product domain, for example district, building topology and also geometries in some use cases (see Table 15). Table 15 also shows that data from behavior, metering, and energy domain are essential for a project with the topic smart city like DAREED. Furthermore, the control and communication domains are not essential in DAREED, since the project does not focus on the direct control mechanism and different communication protocols.

The step 4 of the methodology is “Define data requirements.” As presented in Table 15, the use cases in DAREED project require and generate data from six specific domains and cross domain. There are specific data requirements for each domain which are then listed in Table 16. The requirements for concepts, properties, and their relations are illustrated in a simplified UML class diagram that can be seen in Figure 10 Simplified UML class diagram to highlight relations between concepts of UC-DAREED. The diagram also shows the relationships between data from the domains.

Table 15 Relevant data domain in DAREED project

Use case	Product	Devices	Behavior	Building Data	Energy	Geolocation and Weather	Cross domain
UC-DAREED-1	x		x	x			x
UC-DAREED-2	x	x		x	x	x	x
UC-DAREED-3	x		x		x		x

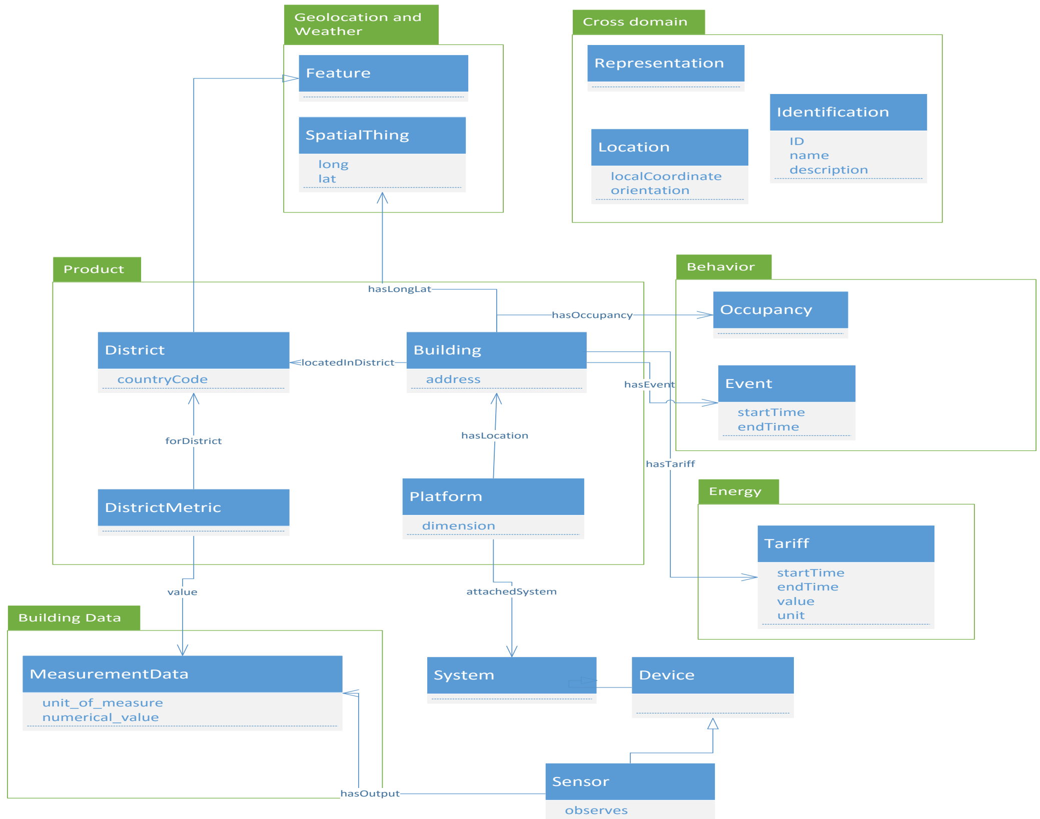

Figure 10 Simplified UML class diagram to highlight relations between concepts of UC-DAREED

Table 16 Specific requirements for each data domain - UC-DAREED

Domain	Specific requirements
Product	• Representation of whole building level • Standard typology of buildings: library, restaurant, etc. • Widely-used properties:address, phone, geo, place, event • Description of shapes
Device	• Observation properties, sensing methods, output description (SSO pattern) • Deployment and placement • Support the modelling of sensor typology
Behavior	• Models of the information about the user events and occupancies that affect the energy consumption
Communications and Data	• Flexible representation of different metrics, KPIs and metering data
Energy	• Modes of energy tariffs and required parameters for energy simulation
District, Geolocation	• Geo-Representation of countries, cities, districts

and weather	•	Simple geo shapes (polygon)
District, Geolocation and weather	•	Basic representation about spatially-located things, latitude, longitude

Cross Domain	**Specific requirements**
Identification	• Identification: ID, name and description of an object
Representation	• Graphical or formal representation of an object
Location	• Representation of relative locations of devices, behavior, building, etc.

UC-CASCADE Energy and maintenance action management

This use case is concerned with the energy and maintenance action management as the scope of the CASCADE project. Table 17 gives a description of this use case as taken from the LBD wiki [7].

Table 17 High level use case - Energy and maintenance action management

Tag	Description
Title	Energy and maintenance action management
Description	This use case focuses on a systematic way to plan maintenance related actions including basic finicalities like task and responsibilities assignation to people and time planning but also advanced functionalities like considerations on actions related energy savings, implementation costs and payback period calculation.
Objectives	Automatizing and Systematizing the energy and maintenance action management
Stakeholders	• Building owner, a person or organization who owns the building and assigns the maintenance activities to the maintenance engineers based on the considerations related to energy savings, implementation costs and payback period. • Engineer, engineers or organizations who implement the automatic and systematic energy and maintenance
Data Domains	Products, Device, Communications and Data, Building Behavior
LD Benefits	• Interlinks the data from different data sources and applications • Enables interoperability between data models
Challenges	On-demand data integration
BLC Stage Data Consumed	Operation
BLC Stage Data Generated	Operation, Design

External Sources	CASCADE website (http://www.cascade-eu.org/)
Available Datasets	<none>
Wiki Contributor	Hendro Wicaksono (KIT)

Table 18 defines the processes and BLC stages in the CASCADE use case (step 1 of the methodology).

Table 18 BLC stages and processes in UC-CASCADE use case

Code	Name	Description	BLC Stage
P01	Improvement Opportunities/Suggestions	Recognized ways of correcting/fixing inefficiencies, failures, leaks, pressure drops, damaged components, etc.	Operation
P02	Pre-populated Energy Audit Items	cost-effective methods for ensuring reliability, safety, and energy efficiency	Operation
P03	Fault detection diagnosis alarms (FDD)	processes the message FDD signal from FDD software	Operation
P04	BMS alarms	processes filtered alarms in BMS/SCADA	Operation

Table 19 gives a description of the domains of interest as they relate to this use cases.

Table 19 Specific concepts and requirements for each data domain - UC-CASCADE

Domain	Specific requirements
Product	• Widely-used properties for the description of the energy consumption
Behavior	• The use cases requires data about activities in the building, especially the ones related to operation and maintenance.
Devices	• The use case requires representation of sensors, actuators and other equipment such as AHU fan, filter, etc.
Communications	• It represent the communication methods and protocols for data transmission within the integrated system.
and Data	• The use case needs representation of metering data outputted by the sensors. There are different types of sensors that observe different
Cross Domain	**Specific requirements**
Identification	• Common identification of objects such as ID, name and description
Location	• Relative location between objects
Representation	• Geometric and formal representations of objects

The stakeholders mentioned in Table 17 generate and process data from the domains shown in Table 19 (step 3 of the methodology for defining data domains) in order to complete the processes defined in the first step of the methodology. Figure 11 depicts the simplified UML class diagram that illustrates the important concepts from each domain and their relationships.

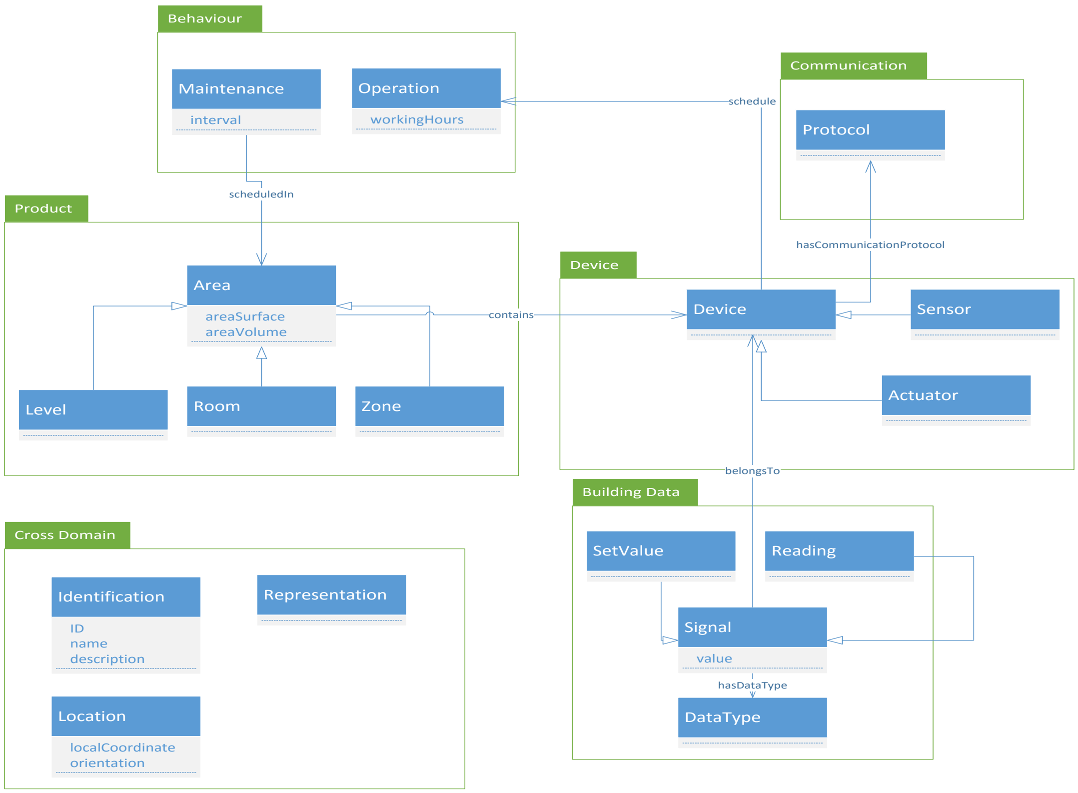

Figure 11 Simplified UML class diagram to highlight relations between concepts of UC-CASCADE

UC-SEAM4US 'Sustainable Energy Management for Underground Stations'

Table 20 gives a description of this use case as taken from the LBD wiki.

Table 20 High Level Use Case Description - Sustainable Energy Management for Underground Stations'

Tag	Description
Title	Sustainable Energy Management System for Underground Stations
Description	This use case is concerned with achieving energy efficiency in metro stations. An advanced energy management system has been developed, involving model based control of forced ventilation, lighting and passenger transfer systems. It mainly refers to the operation stage of the BLC but it also includes functionalities concerning the retrofitting/refurbishment/reconfiguration phase.
Objectives	Implementing a large case study of optimal control of systems in public spaces
Stakeholders	Project Engineers

	Line/Station Operators/Managers/Employees
Data Domains	Building Control, Behavior, Communication and Data, Energy, Geolocation and Weather
LD Benefits	Prediction of station performance under different control conditions Calculation, for every control cycle, of optimal set points, regarding both consumption and comfort, in the current conditions Modeling of occupancy and flows
Challenges	Holistic control of all sub-systems, components and equipment of the station and the combination of information from all connected devices, from the Internet and from energy service providers to achieve efficient control, taking into account the users' needs and preferences. Measurement and verification of the forced ventilation system retrofit, because of the multiplicity of external influencing factors that have seasonal dynamics.
BLC Stage Consumed	Operation, Re-design
BLC Stage Data Generated	Operation, Re-design
Available Datasets	<none>
Wiki Contributor	Nick Kaklanis (CERTH)

In addition, Table 21 depicts the defined stages and processes (Task 1 of the methodology) in more detail. Then we go into slightly more detail regarding the Data domains (Task 3) to provide a quick reference to other use cases which are interested in similar data domains. Along with high-level data domains, it is also recommended to begin to identify the high-level concepts and requirements for each domain and cross-domain concepts, those which can be applied to multiple domains.

Table 22 gives a high level overview of these concepts and their relation to this use case.

Table 21 The different stages and processes within UC-SEAM4US

Code	Name	Description	BLC Stage
S00	Operation	Includes all day to day activity of the in use building.	Operation
S01	Re-design	Covers all changes to the operational building.	Re-design
P02	Control of the energy management in public spaces.	Implementation of optimal control of ventilation, lighting and passenger transfer systems in public spaces.	Operation

Table 22 Specific concepts and requirements for each data domain - UC-SEAM4US

Domain	Specific requirements
Energy	Widely-used properties for the description of the energy consumption
Behavior	Observation properties and sensing methods for the identification of the number of occupants
Control	Properties for enabling the control of the status of the controlled devices
Communication	Basic representation of the required concepts for enabling the Data Base information exchange
and Data	Widely used properties for representing metrics and monitored data from sensors (i.e. Absolute Pressure, Differential Pressure, Solar Radiation Concetration of CO2, PM10 particles, Air Change Rate, Air Flow Rate etc) Support the modelling of sensor typology
Weather	Widely-used properties for the representation of weather conditions (i.e. temperature, humidity, wind speed and wind direction)
Cross Domain	Specific requirements
Identification	Properties for uniquely identifying objects (i.e name and category)
Time	Widely-used properties for the representation of date and time; format yyyy-mm-dd and hh:mm:ss
Location	Basic description of the placement of spatially-located things/sensors/devices etc

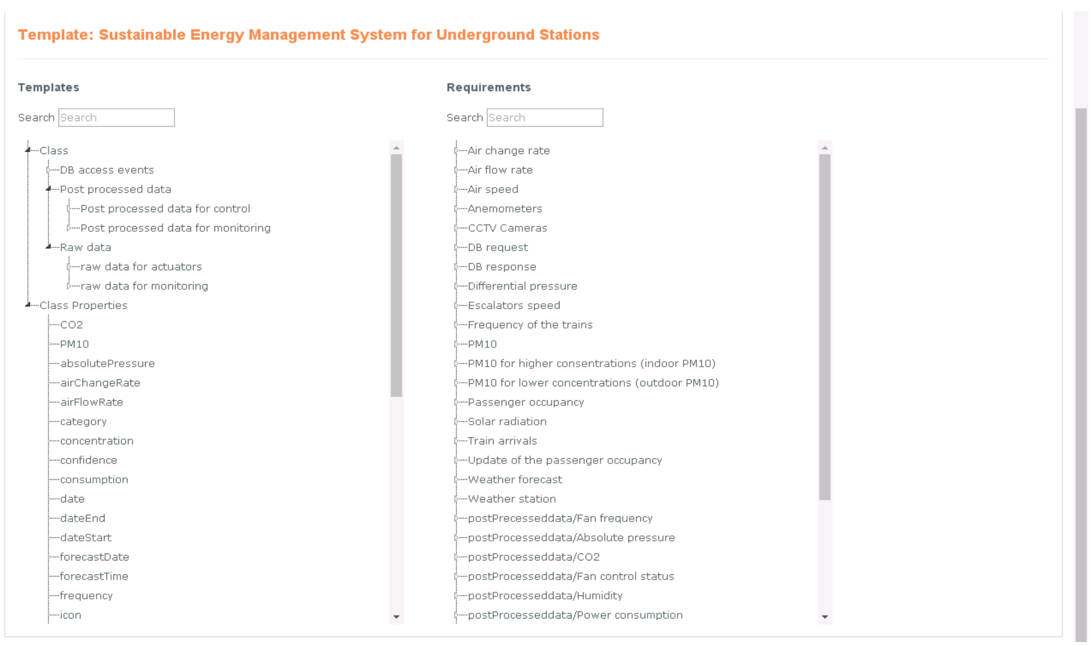

Figure 12 UC-SEAM4US Data Exchanges in the BIM*Q Tool (Left Classes by domains, Right Exchange Requirements)

Figure 12 provides a screen shot of the data requirements as defined from the analysis of the respective project and presented in the BIM*Q tool. Finally, Figure 13, provides a concept diagram related to the data domains and the relations between those concepts.

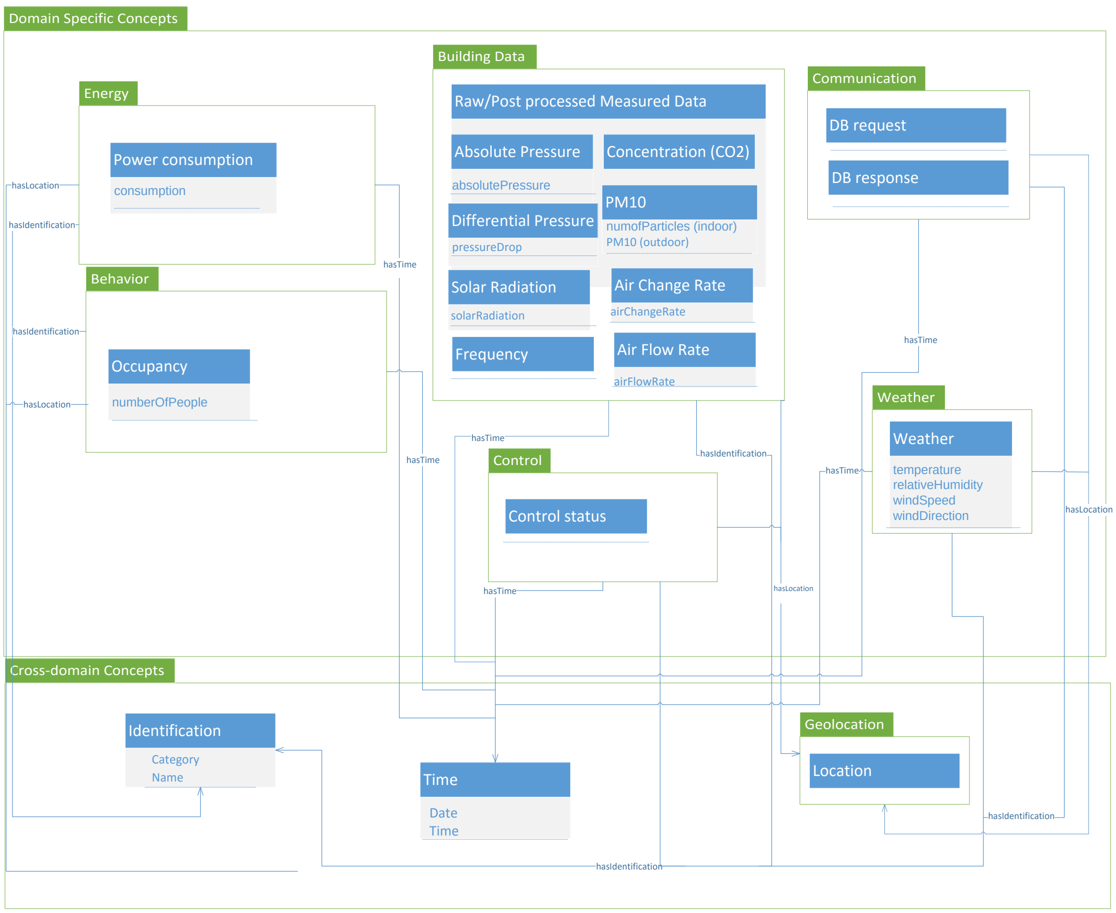

Figure 13 Simplified UML class diagram to highlight relations between concepts – UC-SEAM4US

Analysis of Use Cases

In the previous sections we presented steps 1-4 of the SWIMing methodology, modelled using the BIM*Q tool and applied to seven use cases, one exploratory and six taken from existing EeB projects. In this section we analyze the data requirements to identify potential areas of harmonization at a conceptual level. This harmonization will inform the process of alignment to standards which is being conducted and will be presented in D2.3. The purpose therefore of this section is to enable the identification of specific domains which are then aligned with a particular standard, e.g. IFC. It also supports the identification of potential areas for linking between domains, for example through the shared use of concepts like space. It begins with an overview of the different domains represented across use cases.

Overview of Domains across Use Cases

Table 23 and Table 24 show the high level domains identified (specific and cross domains) for each use case. Here where each use cases is making use of a domain, it is indicated with an 'X'. Any concept which is not represented at least twice is not included. It should be remembered, that not all data requirements for the use cases are captured in BIM*Q and therefore, this list should not be considered complete. It is intended as part of an ongoing process of harmonization of data requirements across use cases, and is therefore subject to adaptation.

Table 23 Domain-specific concepts across use cases (where representation is > 1)

Use case	Product	Devices	Behavior	Control	Communications and Data	Energy	District, Geolocation and Weather	Actor
UC-SIM	X		X				X	
UC-EEMBEDDED	X	X	X	X	X	X	X	
UC-STREAMER	X	X					X	X
UC-OPTEEMAL	X					X	X	X
UC-DAREED-1	X		X		X			
UC-DAREED-2	X	X			X	X	X	
UC-DAREED-3	X		X			X		
UC-CASCADE	X	X	X		X			
UC-SEAM4US			X	X	X		X	

Table 24 Cross-domain concepts across use cases (where representation > 1)

Use case	Identification	Location/Placement	Space	Representation/Geometry
UC-SIM	X	X	X	
UC-EEMBEDDED	X	X	X	X
UC-STREAMER	X	X	X	X
UC-OPTEEMAL	X	X	X	X
UC-DAREED-all	X	X		X
UC-CASCADE	X	X		X
UC-SEAM4US	X	X		

Overview of Concepts in Specific Domains

In this section we examine concepts within each specific domain which are represented across use cases to identify potential concepts for harmonization. If a use case is not represent with an 'X' a column, it has no concepts within that domain which relate to another concept in one of the other use cases.

Product Domain

Table 25 Product concepts across use cases (where representation is > 1)

Use case	Building	Storey	Room
UC-SIM	X		
UC-EEMBEDDED	X	X	
UC-STREAMER	X	X	X
UC-OPTEEMAL	X	X	
UC-DAREED-all	X		
UC-CASCADE			X
UC-SEAM4US			

Device Domain

Table 26 Device concepts across use cases (where representation is > 1)

Use case	Sensor	Actuator
UC-EEMBEDDED	X	X
UC-STREAMER		
UC-DAREED-all	X	
UC-CASCADE	X	X

Communications and Data Domain

Table 27 Product concepts across use cases (where representation is > 1)

Use case	Data Point/Reading/Measurement	Interface/Protocol
UC-EEMBEDDED	X	X
UC-STREAMER		
UC-OPTEEMAL		
UC-DAREED-all		
UC-CASCADE	X	X
UC-SEAM4US	X	

Behavior Domain

Table 28 Behavior concepts across use cases (where representation is > 1)

Use case	Occupancy	Device Behavior
UC-SIM	X	
UC-EEMBEDDED	X	X
UC-DAREED-all	X	
UC-CASCADE		X
UC-SEAM4US	X	

Energy Domain

Table 29 Energy concepts across use cases (where representation is > 1)

Use case	Tariff
UC-EEMBEDDED	X
UC-OPTEEMAL	
UC-DAREED-all	X
UC-SEAM4US	

District, Geolocation, Weather Domain

Table 30 District, Geolocation and Weather domain concepts across use cases (where representation is > 1)

Use case	Site
UC-SIM	
UC-EEMBEDDED	X
UC-STREAMER	X
UC-OPTEEMAL	X
UC-DAREED-all	
UC-SEAM4US	

Actor Domain

Table 31 Actor concepts across use cases (where representation is > 1)

Use case	User Model
UC-STREAMER	X
UC-OPTEEMAL	X

Control Domain

While two use cases explicitly refer to building control, there are currently no conceptual alignments identified as yet between the presented use cases.

Discussion regarding Analysis and Recommendations

The previous section presented an overview of shared domains and concepts across the seven EeB use cases. As a result, the following observations have been made. To begin, the variation within EeB projects and their different views on data representation mean it may be possible to classify use case concepts under one or more domains. It is also not always possible to include all concepts, as the level and depth of projects is considerable, covering many different domains in differing levels of granularity. Nonetheless, the process of examining the use cases has led to some interesting findings. As can be seen, certain domains have consistent concepts represented as indicated by Table 25-Table 31. These concepts should be aligned with standards and targeted across EeB projects to ensure consistent representations of data.

During the process of defining use cases, it has also become apparent that certain concepts can be shared across specific domains. It is therefore suggested that these cross domain concepts be leveraged to support alignments between concepts in different specific domains. For example, the spatial concept and spatial relations are used across use cases, and therefore, space could be a potential concept for managing equivalence relations, allowing one domain to reference a space which is also reference by another domain. The location concept also is something which is shared for different domains. Here we suggest also adapting our own classification to no longer include geolocation as a specific domain, but rather a member of the cross-domain location concept. The use of the concept of site may also be a good basis for linking building and district models. For identification, Linked Data and the Resource Description Framework provides a global identification system based on Universal Resource Indicators (URI), nonetheless, identification can include other concepts, like name, and type, and so, once again, a standard is required for consistent representation of identification.

1 Summary and Conclusion

This deliverable continue the work presented in D1.1 [8] through the exploration of seven use cases which address three distinct stages of the buildings life cycle (BLC), design, operation and re-design. Six of these use cases are being actively developed with corresponding H2020 EeB projects. The deliverable demonstrates the application of the SWIMing methodology, defined in D2.2 [1] and which has been developed to support the capture of business use cases in the EeB domain. The deliverable covers the first four steps of the methodology, and presents the findings of conducting these steps across the seven use cases. These four steps cover the identification of building life cycle stages (and processes within), the identification of stakeholders and the identification of data domains of interest, and the further capture of more specific data requirements at a conceptual level. The deliverable presents a high level overview of the fourth step across the use cases, for the purpose of the harmonization of concepts. For this task, use case data domains have been classified as both specific and cross domain, the former having specific properties which are not shared with other domains.

Through this process several specific domains and concepts within those domains have been identified which are shared across the use cases and which make good candidates for alignments with existing standards. This process of alignment has already begun, and the initial steps are presented in D2.2 [1] and will be presented again in D2.3. This deliverable therefore provides recommendations about which concepts are shared across use cases and which concepts are best suited for enabling alignments and linking between data domains.

The methodology has been enacted through the use of a tool called BIM*Q. BIM*Q can support the modelling of use cases, the identification of data requirements and their alignment with existing models for the purpose of publishing data through a web-based interface, which are then stored in a shared repository. Through this process of modelling and identification of alignments, the BIM*Q tools is intended to become a go to place for those developing use cases in the EeB domain. Through the interface, use cases with similar names and descriptions can be identified and the different data requirements and data domains covered by that use case can be analyzed. In this way, projects can use what has been developed in other projects as a basis for their own.

By taking this approach, the task of ensuring interoperability of the developed models with existing approaches becomes more efficient. The adapted IDM methodology and its application through the use of the BIM*Q tool have been demonstrated in this deliverable with the focus on the development of high level use cases and alignments and harmonization between concepts in EeB projects.

The BIM*Q tool has several advantages over the traditional IDM approach, based on documents and spreadsheets for capturing data exchanges.

1. All identified data exchanges are available in one central repository accessible through a web browser,
2. Multiple domain experts can collaboratively work on the tool in real time over the
3. The data stored in BIM*Q can be further semantically enriched with additional meta-data to help with classification and identification of use cases.

In the case of 3) the BIM*Q tool is being extended to support new functionalities, for example, word matching of concept terms to the IFC standard.

The next steps are now to further analyze the use cases currently stored in BIM*Q, and which are being actively added, and continue the process of classification of data requirements by domains. In this way, developers of new use cases will be able to quickly identify data domains and concepts of interest, as well as concepts which can be used to support the alignment of different models. In addition, the alignment process of concepts with standards (IFC, CityGML, gbXML, etc.) will continue, and these alignments will be presented in D2.3.

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